FUNCTIONAL ASSESSMENT AND BIOFEEDBACK TREATMENT OF THE UPPER LIMB IN HEMIPLEGIA

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ABSTRACT

The thesis explored three, albeit related, topics. As a prelude to treatment evaluation, a reliable, brief and standardised test of upper limb function for use with hemiplegic patients was developed. The brevity of the test derived from the hierarchical order of item difficulty within its constituent subscales. This Action Research Armtest was cross-validated, and proved to have concurrent validity with several scales of the Activities of Daily Living (A.D.L.) test described next.

A similar Guttman scaling exercise was directed at the simplication of A.D.L. assessment. Twelve Guttman scales encompassing seventy five A.D.L. items were detected in a sample of stroke patients with hemiplegia. The derived scales reflected underlying similarity of function and seemed to provide a more logical basis for both assessment and treatment. In addition, savings averaging over fifty per cent in testing were found to be possible by utilising the inherent Guttman structure. Interestingly, the majority of the A.D.L. scales related clearly to upper limb function.

The Armtest described earlier was next used to evaluate electromyogram biofeedback treatment of the upper limb in hemiplegia. No significant treatment effect was found amongst the more severely impaired patients, however a significant effect on the magnitude of recovery, as assessed by the Armtest, was found for a less severely impaired patient group. The Armtest appeared to hold some promise as a predictor of treatment outcome. An explanation was proposed to explain apparent discrepancies between previous experimental findings, and recommendations were made regarding future experimental work.

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DECLARATION

I hereby declare that this thesis has been entirely composed by me alone and represents my own work.

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CHAPTER ONE

HEMIPLEGIA

Hemiplegia, a one-sided paralysis resulting from an upper motor neuron lesion, is one of the commonest types of severe physical disability in our community (Harris, 1971). The side of the body impaired is normally contralateral to the site of the lesion, owing to the decussation of the pyramidal cells. The hemiplegic may, however, be affected in other respects also. If the lesion is sited in the dominant hemisphere, some impairment of linguistic functions may occur; and disturbances of sensation and the kinaesthetic sense are common.

Hemiplegia can result from many different types of lesion, variously situated in the central nervous system, and varies widely in the degree and permanence of the impairment resulting. It will therefore be of benefit to consider some of these aspects before proceeding to a more detailed consideration of those aspects of hemiplegia which are of particular relevance to the research reported in this thesis.

The Pathology

Lesions involving the upper motor neuron, at a wide variety of locations and resulting from many different kinds of pathological processes, produce

paralysis, alterations of muscle tone and alterations of reflex activity. Lesions destroying the upper motor neuron are rarely selective or complete and frequently involve adjacent pathways and nuclear structures. The degree of paresis or paralysis has not been found to bear a direct relationship to the size of the lesion or to the extent of involvement of the corticospinal tract (Walsh, 1978). Destruction of the upper motor neuron may result from vascular disease, trauma, neoplasm and infectious and degenerative diseases. Spinal lesions, most commonly the result of trauma, are usually bilateral and cause a paraplegia, whilst unilateral lesions in the cerebral hemisphere and brain stem produce contralateral paralysis, usually hemiplegia.

The most common of these are disorders of the cerebral circulation or strokes. According to the epidemiological study of Whisnant, Fitzgibbon, Kurland & Sayre (1971) of 194 strokes occurring in one year, in a population of 100,000, 146 (75%) were attributed to infarction, and 10% to cerebral haemorrhage. Walton (1977) attributed a further 8% of strokes to subarachnoid haemorrhage. The pattern of impairment which results varies to some extent according to both the site and the extent of the lesion.

Cerebral thrombosis is the most common type of cerebral vascular lesion, and the middle cerebral

artery and its branches or the main trunk of the carotid artery are involved with the greatest frequency. Sudden occlusion of a major cerebral vessel deprives local regions of neural tissue of blood and oxygen, causing the tissue to undergo necrosis. Tissue surrounding the infarcted area becomes congested and oedematous.

Freytag (1968) found from a study of 393 cases of cerebral haemorrhage that 42% were in the region of the internal capsule and corpus striatum, an area of the brain where several nerve pathways converge and where comparatively localised damage might result in a variety of effects. Interruption of the blood supply to a major cerebral artery can result in infarction of a large area of cortex or sub-cortical tissue.

The effects of any surgical intervention also require to be taken into account, when excision of intact brain tissue may be necessary, as for example in the course of surgery for aneurysm. But reference must be made to other types of pathology which may result in hemiplegia or in degrees of weakness or hemiparesis. The first of these is of subdural haematoma, an encysted collection of blood between the dura mater and the arachnoid, which may result in compression of the brain. Head injuries, whether open or closed, are another common cause of hemiplegia and infection by a neuro-

tropic virus, although a relatively rare cause may also result in a residual hemiplegic impairment.

Incidence and Prevalence

Cerebro-vascular accidents, the third commonest cause of death, are also the commonest cause of severe chronic disability in the community (Harris, 1971). The incidence of C.V.A. (stroke) is approximately 2/1000 per year. There are approximately 120,000 new cases each year in England and Wales of which half are fatal and perhaps 35,000 are left with significant disability. It is estimated that there are 130,000 people with significant impairment from stroke living in the community and 93,000 who are severely or very severely handicapped, most frequently with paralysis of the arm and leg. A number of hemiplegics also have serious impairment of speech (aphasia). Although the problem is one that affects particularly the older section of the population, a very substantial fraction are under 70, and a quarter of cases occur in persons under 60.

Signs and Symptoms

In the majority of patients symptoms are of sudden onset. Initial symptoms may be both focal and general in character. Generalized symptoms may include headache, vomiting, convulsions and coma.

Focal symptoms, such as paralysis, sensory loss, or impairment of speech are related to the site of the lesion and the structures involved. Immediately after the vascular lesion, the paralyzed limbs contralateral to the lesion usually are completely flaccid and the myotatic reflexes are depressed or absent. After the period of neural shock has passed, the myotatic reflexes reappear in an exaggerated form in the paralyzed limbs. The superficial abdominal reflexes, elicited by stroking the skin over the abdomen, and the cremasteric reflexes in the male disappear on the side of the paralysis. The plantar response, elicited by stroking the sole of the foot, becomes extensor. The latter response, known as the sign of Babinski, consists of extension of the great toe and fanning of the other toes. Although the sign of Babinski is of great clinical importance, the physiological mechanism underlying is not understood.

After a variable period of time, usually two or three weeks, muscle tone gradually returns in the affected limb and ultimately exceeds that of the normal side. This exaggeration of muscle tone is referred to as spasticity. The exaggeration of muscle tone may not be exhibited by all muscles in the affected limbs. In the affected upper extremity spasticity is present particularly in the adductors and internal rotators of the shoulder, in the

flexors of the elbow, wrist and digits and in the pronators of the forearm. In the affected lower extremity spasticity develops in the adductors of the hip, the extensors of the hip and knee and in the plantar-flexors of foot and toes. Spasticity is characterized by increased resistance to passive movement, hyperactive myotatic reflexes and the presence of clonus. Clonus is a manifestation of the exaggerated stretch reflex in which the contractions of one muscle group are sufficient to stretch antagonistic muscle groups and initiate myotatic responses in that muscle group. Clonus has a tendency to persist in a synchronized manner. In some instances the threshold for this extreme exaggeration of the myotatic reflex is so low that passively moving a limb may initiate it.

The paralysis, which may appear complete at the onset of the C.V.A. tends to become less severe in time. Even the weakness tends ultimately to involve one limb more than the other. The motor functions that are affected most are those associated with fine, skilled movements; these movements also show the smallest amount of recovery with time. The movements that are grosser and less skilled, and those which involve a whole limb, are relatively less affected and usually show considerable recovery. Because of the distribution of muscular spasticity,

flexion movements tend to be stronger in the upper extremity, while extensor movements are strongest in the lower extremity. Hence patients normally recover functional use of the lower limb first. Atrophy of the type seen with lower motor neuron lesions does not occur with upper motor neuron lesions. However, after a period of years some atrophy from disuse becomes evident.

Upper motor neuron syndromes resulting from lesions in the brain stem produce disturbances of motor function similar to those described above, and in addition they usually involve particular cranial nerves and sometimes sensory pathways. Mid-brain lesions frequently produce a contralateral hemiplegia and ipsilateral paralysis of the oculomotor nerve. Lesions in the ventral part of the pons may involve the corticospinal tract and fibres of the abducens and facial nerves, producing a contralateral hemiplegia and corresponding ipsilateral cranial nerve palsies. In the medulla lesions in, or near, the pyramid usually also involve emerging fibres of the hypoglossal nerve.

Prognosis

Many hemiplegics recover considerable motor function in time, in spite of the fact that there is great clumsiness in carrying out simple, skilled movements. Those who become ambulatory have a

characteristic gait. The paralyzed leg is circumducted at the hip en bloc and swung forward because of the difficulty in flexing the knee. The foot is plantar-flexed and the toe of the shoe is dragged in a circular fashion. The arm on the affected side is flexed at the elbow and wrist, the forearm is pronated, and the fingers are flexed. The arm may be held close to the body, but if the arm is swung at all in walking, it moves primarily at the shoulder.

Certain patient attributes have been identified as being associated with a better prognosis for functional recovery amongst hemiplegic patients. Feigenson, McCarthy, Greenberg & Feigenson (1977) found that severity of weakness on admission, a long interval between onset and admission, and the presence of severe perceptual or cognitive deficits in addition to a motor deficit were related to increased length of stay and to an unfavourable outcome as measured by ability to perform Activities of Daily Living. Granger, Sherwood & Greer (1977), paralleled Feigenson et al. in discerning a relationship between admission score on the Barthel index (Mahoney & Barthel, (1965)), a measure of A.D.L., and rehabilitation outcome. Patients most likely to gain through rehabilitation had acute stroke unit admission Barthel indices of 21 or more and rehabilitation transfer Barthel scores of 41 or more. Bourestom & Howard (1969) found that the Performance IQ of the Wechesler Adult Intelligence Scale, itself

a measure of motor performance, discriminated between patients achieving differing degrees of improvement in self-care activities, again using performances of A.D.L. as a criterion; but this relationship held only for patients with low self-care admission scores.

Social class, dysphasia, and hemisensory deficit have been claimed to be unrelated to prognosis (Feigenson et al. 1977; Powell, Diller & Grynbaum 1976); however, Basmajian (1978) found a negative relationship between sensory deficit and degree of recovery, when biofeedback of electromyogram was administered as treatment. Wahle (1973) reported a negative relationship between loss of proprioception and outcome of hemiplegia. Wahle also pointed to the poorer recovery of function in the upper extremity, less than 10% recovering full use of the hand, as compared to that of the leg. This may be explained in terms of the differential degree of fine motor control required for upper as compared to lower extremity function. Topography of representation in the motor cortex may also be relevant in this regard.

In addition to other prognostic indicators, age at time of trauma, although not a discriminator with adults, has been found to be related to outcome for young children. Obrador (1964) found a remarkable degree of "functional plasticity" in children undergoing hemispherectomy, while McFie (1961) and Netley (1972) suggested that transfer or compensation

of function was optimal up to the age of 17-24 months. The finding that functional recovery was also related to the rate of destruction of cortical tissue was of further practical and theoretical interest. Finger, Walbran & Stein (1973) concluded from a review of animal studies that morbidity and mortality in animals operated on using a single stage lesion, was greater than in multi-stage lesion procedures, in spite of histological evidence demonstrating greater damage in the multi-stage operation. Olbrich (1972) found a degree of association between the rate of development of cerebral pathology, and severity of deficit on a reaction time task; clinically, aphasia is more often seen in patients with a rapidly expanding or single stage lesion than in those with a slowly growing lesion.

Current Practice

Langton Hewer (1974) commented that rehabilitation for hemiplegic patients had, in many hospitals, not changed significantly within the last twenty years. The average patient admitted after an acute stroke received thirty minutes of physiotherapy per day and ten minutes speech therapy if dysphasic. Brocklehurst (1978) reported that treatment lasting over four months was more likely to be received by those with the poorest prognosis, making the worst progress, and

suffering the most depression. Fifty per cent of those receiving physiotherapy for over six months showed no recovery throughout the whole of one year. Clearly, should such findings be replicable elsewhere, considerable scope exists for improvement in the management of these patients.

Following the initial medical management of the trauma, or other aetiology of the stroke, assessment and treatment are the critical professional activities performed upon the patient in hospital. Additional assessment of the patient is likely to be carried out separately by physiotherapists, occupational and speech therapists, in a variety of ways for differing purposes. Comprehensive yet reliable measures of limb function are a pre-requisite for the evaluation of many procedures involving the rehabilitation of the hemiplegic. They may also serve in making predictions regarding likely recovery: a necessity, since intensive therapy cannot be given to everyone and ought perhaps be reserved for those more likely to show some degree of useful recovery. The type of evaluation which is most appropriate might be expected to vary according to the purpose for which it was intended. For everyday clinical purposes, a broadly ranging assessment of Activities of Daily Living would perhaps be required by the occupational therapist, while the physiotherapist would measure muscle

power, range and pattern of movement. In assessing scientifically a treatment which had a highly specific effect, different properties might be required of the measuring instrument; whereas in determining prognosis, the predictor would require to fulfil mainly statistical criteria. There has been an unfortunate tendency towards proliferation of non-standard measures, in particular of A.D.L. and limb function, developed at a variety of centres for differing purposes, and frequently in isolation from psychometric principles of measurement, test construction and validation. Part of the work reported later is intended as a contribution in that direction.

Bobath (1970) has described a sequence in the rehabilitation of the hemiplegic which parallels standard practice in many rehabilitation hospitals throughout the country. Bobath has devised a system of rehabilitation which relies heavily upon clinical experience, and requires a prolonged period of training in order to acquire proficiency in its application. Since the procedures are so highly detailed, it is impossible to fully describe them here, where a brief review only must suffice. The reader wishing a fuller account is referred Bobath's (1970) text. Bobath sees the rehabilitation of the hemiplegic from a physiotherapy point of view, as falling into two distinct areas: those of

assessment and of rehabilitation. Four basic approaches to assessment of the hemiplegic are possible. These are the assessment of functional abilities, the assessment of ranges of movement, the assessment of muscle power, and the assessment of motor patterns. Bobath's preference is particularly for the latter, which consists of qualitative assessment of deficits in normal postural reaction patterns. The assessment falls naturally into four divisions. The first is a sensory assessment, relating to the senses of position and movement, of pressure and touch, and of stereognosis. The second aspect of assessment relates to tonus, and to the degree of flaccidity or spasticity present. The third aspect of assessment relates to the quality of movement patterns. These are scored for the positions of supine, sitting and standing, and relate to movements of the arms, and shoulder girdle, the wrist and fingers, and the pelvis, leg and foot. This assessment, in addition to the assessments mentioned above relies on clinical judgement, utilising a standard clinical rating scale. Lastly, assessment includes an evaluation of balance and protective reactions. Bobath does not under-estimate the importance of assessment, since the programme of therapy is grounded firmly in an evaluation of deficient postural reaction patterns as detected by the

assessment procedures above.

Treatment naturally varies according to the pattern of impairment seen in the individual patient, whose problem is seen as being his inability to direct nervous impulses to his muscles in the many varied ways and different combinations of patterns used by a person with an intact nervous system. One of the principal aims is to change the abnormal, stereo-typed patterns of movement. Bobath described a range of exercises, conducted to assist in achievement of these treatment aims. Bobath found that movements could be facilitated by placing the patient in key postures determined by a profound knowledge of physiology and anatomy, which had the effect, for instance, of minimising the degree of spasticity evident. Bobath also borrowed freely from the techniques developed by other workers in this area. Her armamentarium therefore included use of heavy resistance exercises (Walters 1967); of associated reactions and mass synergies (Brunnström 1956, 1970; Knott & Voss 1973); of reflex inhibiting patterns or postures; of sensory stimulation (Goff 1969); and of various pharmacological and technological measures, such as the use of drugs to inhibit spasticity, and of irradiation by short-wave diathermy (Knott 1967).

A failing common to the above current

physiotherapeutic procedures has however been the lack of any scientifically rigorous assessment, a lack shared by certain medical procedures (Cochrane, 1972; Mather, Pearson, Read, Shaw, Steed, Thorne, Jone, Guerrier, Eravt, McHugh, Chowdhury, Jafary & Wallace 1971). Physiotherapy has been as prone to fads in treatment as has medicine: direct electrical stimulation of muscles, or faradism is one treatment which has suffered a recent decline in popularity; and the questions of whether the value of certain types of massage extends beyond temporary relief, or of whether passive movement of a limb yields any demonstrable therapeutic effect, await experimental evaluation. The evolution of physiotherapy from the status of a craft to recognition as a true applied science will surely hinge upon the adoption of such a self-critical, scientific, manner of proceeding. Prior to evaluation of treatments however, the development of the means wherewith to assess them is necessary. It is here that the psychometric expertise of clinical psychology may be of assistance. It is envisaged that the upper extremity function test, the development of which is described in Chapter 4 will have some future applicability in this regard.

Biofeedback, a treatment technique which appears to lie at the juncture of learning theory and cybernetics, is one of the most recent to be applied to hemiplegia. It has however, in its application, tended to suffer the same lack of

scientific rigour in evaluation as has befallen many procedures in this area. The experiments reported in this thesis seek to evaluate the efficacy of biofeedback with the electromyogram in facilitating recovery of upper limb use with some hemiplegic patients.

Models of Recovery

It is perhaps worth considering the mechanisms whereby recovery, when it does occur, takes place. This is not only important for the purposes of understanding the therapeutic effect of current physiotherapies, but may also be of relevance in understanding the therapeutic effect of E.M.G. biofeedback training. Several mechanisms have been proposed which are not necessarily mutually exclusive, and which are posited to act at differing physiological levels in the patient. An excellent review of the recent state of knowledge in this area was provided by Stein Rosen & Butters (1974); Luria (1963, 1978) are also relevant.

Explanations at the neuronal level seek to account for recovery in terms of the development of extra synaptic connections in place of those damaged by the lesion. On the axonal growth hypothesis, certain nerve fibres are postulated to grow when transsected, to invade the area of damage, and, advancing along blood vessels, to

enter adrinergically innervated tissue. Björklund and Stenevi (1971) demonstrated this property in certain catecholaminergic fibres. Alternatively or additionally, by axonal collateral sprouting, intact adjacent nerve ends are regarded as making synaptic contact with denervated membrane. One might tend to assume that activity under the two heads described above should necessarily be beneficial: however, on reflection, would the introduction of an essentially random addition to the neuronal network, not tend perhaps to add confusion to a previously orderly set of connections? A similar difficulty arises with the neurohumoral explanation of denervation supersensitivity whereby a denervated neuron may acquire supersensitivity to its customary neurotransmitter.

The occurrence of a temporary state of inhibition in cortical cells adjacent to the lesion is a well-known phenomenon, recovery from which has been advanced by Luria (1963) as an additional partial explanation of recovery of function after brain injury. Indeed, Luria has emphasised pharmacotherapy with C.N.S. stimulants as having an important role in rehabilitation of the brain-injured. Recovery from physiological inhibition due to codema and haemorrhage is a related concept: however, the time course of such recovery is relatively too swift to account for

behavioural recovery occurring over a period of months.

The concept of hierarchical, duplicated, or in some sense holographic representation of functions in the cortex is not unique to one authority (Hughlings Jackson 1874; Luria 1978), and moves explanation to a higher level of abstraction. Luria, for instance, holds that many activities are represented atvarying levels of complexity, both at specific sites, and as patterns involving simultaneous activity across the cortex. It would follow from such an hypothesis that an engram which had been lost might be substituted for, or indeed reconstructed, as it were, from "archive". A related, though distinct notion, is that of behavioural substitution (Luria, 1963) whereby an alternative neural route, as it were, or strategy, is developed to subsume the lost function. An example of this was afforded by a lady, seen by the writer, who, although the half of her face sagged following an acoustic neuroma, was yet able to lift it upon trying to smile; or a densely hemiplegic patient who was able to flex his otherwise totally flaccid elbow whilst yawning. Luria (1963) cites many more examples as applied to motor patterns. Such a behavioural substitution might arise in an all-or-none insightful way, as has been described in his animal learning

experiments by the famous Gestalt psychologist Wolfgang Köhler (1925): or more gradually by trial and error learning, as has been documented in the experiments of Thorndike (1911) and Skinner (1938).

A more rudimentary form of behavioural substitution, accurring at the motor unit level, is known clinically, and has been described by Marinacci (1955) and Marinacci & Horande (1960). This refers to the hypertrophy, through excessive use, of intact motor units of muscles not necessarily identical with those affected by hemiplegia, but nevertheless capable of generating a pattern of activity which substitutes in some degree for the motor pattern lost. This process has been considered to lead to the development of giant motor units which serve to compensate in part for the loss of nerve tissue. Marinacci (1955) observed certain motor units to increase in voltage from 0.5μV to 25μV and in duration from 5 m.sec. to 30 m.sec. within a period of 12 to 18 months.

It can therefore be seen that recovery of motor function in the upper extremity of the hemiplegic patient may represent the result of the intricate interplay of a number of as yet imperfectly understood complex processes. By contrast, the question of the efficacy or other-

wise of E.M.G. biofeedback treatment seems almost simple: it nevertheless aids understanding to have a notion of the kinds of processes whereby the patient may achieve "positive feedback".

CHAPTER TWO

FUNCTIONAL ASSESSMENT IN HEMIPLEGIA

Members of several professions are likely to assess the hemiplegic patient. This thesis is particularly concerned with functional, as contrasted with diagnostic assessment, and leaving aside neurological assessment procedures, which are concerned primarily with identification of organic pathology, the two professional groups principally involved in assessing the hemiplegic patient in this way are those of the physiotherapists and of the occupational therapists. It is therefore appropriate here to review the research literature on the above, as a prelude to considering the development work described later in Chapters 4 and 5.

Physiotherapeutic Approaches

Commonly, the first intensive functional assessment of the hemiplegic patient is performed by the physiotherapist. Stichbury (1975) described a careful assessment procedure which considered locomotor ability assessed on the basis of thirtysix progressions of movement, e.g. "supine to prone over right", using a three point scale to describe the quality of the movement. Locomotor ability was

further assessed as to the degree of spasticity evident in the four limbs, when each was moved whilst certain bodily postures was held. A six point scale was used, employing criteria such as "total flexion or extension" "some control of proximal joint" "some evidence of mass action". Stichbury also described an assessment procedure for sensory loss, separately for superficial and deep sensation, and for joint position sense. Sensation was tested using cotton wool for light touch, and a blunt object, such as the end of a pencil for deep sensation. The criteria for superficial sensation required the therapist to make judgements as between "anaesthetic", "hypoaesthetic", "hyperaesthetic" and "normal" and for deep sensation as between nil, partial and full awareness. Stimuli were delivered to areas of the body as per a schematic diagram. Evaluation of joint position sense proceeded on the basis of the therapist's assessment of the subject's awareness of passive movement of his limbs through varying arcs of movement, graded from normal through fine, coarse, gross, and extremes of movement only to unawareness. Data on inter-rater and test-retest reliability were not presented in Stichbury's study, although investigation of these important aspects was said to be in prospect. Alternative protocols for physiotherapy assessment of the hemiplegic patient are available.

Lavigne (1974) developed the original Brunnström (1966) assessment and Bobath (1970) had earlier evolved an entire approach to physiotherapy assessment and treatment of the hemiplegic, which necessitated a prolonged course of training. Lincoln and Leadbitter (1979) published a scale for assessing locomotor ability which was parsimonious of time by virtue of its being Guttman scaled, in that satisfactory performance on certain activities was found reliably to predict performance on others. Four week test-retest reliability was assessed using ten hemiplegic stroke patients thought to have reached a plateau of improvement, and was found to be high for the leg and trunk and arm scales, $r = + 0.93$ and $r = 0.88$ respectively, but less so for the gross movement scale, $r = + 0.66$. Inter-rater reliability was assessed using analysis of variance, where a rater effect ($p < 0.05$) was found for the arm scale, but not for the others. Lincoln and Leadbitter's scale does not include a sensory assessment, although they reported such a scale to be in preparation. Although Lincoln and Leadbitter's scale may be criticised on certain statistical grounds, such as the small sample size for the reliability studies, and certain unsatisfactory reliability estimates, the scale is currently being standardised on a larger sample (Lincoln, 1979), and their study is the first attempt to provide statistical evidence of reliability, whereas elsewhere a bland assurance of

replicability, is judged sufficient.

In clinical practice, physiotherapists sometimes develop local versions of physiotherapy assessment forms, sometimes employing mechanical devices such as dynamometers and goniometers as an adjunct to, or in place of, subjective assessment of muscle power and range of movement, and Bigland and Lippold (1954) reported, that under isometric conditions of contraction, recorded E.M.G. activity closely paralleled the force exerted. However, one should not too readily assume that a measure is any more reliable if taken by such devices, than the subjective measures reviewed above may be. The thesis seeks to test this assumption. From an examination of many physiotherapy assessment protocols undertaken as a preliminary to the E.M.G. biofeedback experiments reported later in this thesis, no readily available measure sufficiently detailed and specific to the upper limb, and of known reliability, could be found.

A more detailed test of upper extremity function only, had however been developed by Carroll (1965). The test utilised a collection of apparatus, described in sufficient detail to allow replication. The test consisted of thirtytwo items, to be attempted with each hand, involving the operations of grasp, grip, lateral prehension, pinch, placing, pronation and supination; the thirtythird item consisted of writing one's name using the dominant hand. Carroll

administered his Upper Extremity Function Test to seventynine patients, who had received diagnoses including upper motor neuron lesion, mixed neurological diseases, rheumatoid arthritis, extrapyramidal lesion, spinal cord lesion, amputation and others. Performance on each test item was scored on a four point scale, as below:

0 : Patient can complete no part of test
1 : Performs test partially
2 : Completes test, but takes abnormally long time or has great difficulty
3 : Performs test normally.

In addition to the U.E.F.T., measures of activities of daily living, (Carroll, 1962), a mental status check list and a grip dynamometer reading were taken. Although no direct statistical comparison of ADL and EUFT scores was made, Carroll concluded on the basis of pilot work with earlier versions of both tests that a degree of correspondence existed. Carroll further reported data on serial evaluation (test-retest) and observer (inter-rater) differences: but the data reported, although impressive, was not subjected to correlational analysis, and sufficient data was not supplied to allow a retrospective calculation to be made. Carroll (1965) intended the U.E.F.T. to be used to identify upper extremity impairment requiring treatment, and to measure changes in hand function with advancing disease, surgical or other treatment. Provided that the test

could satisfy certain statistical criteria of standardisation, in respect of reliability, it was obviously of potential use in evaluating the specific effect of treatments for hemiplegia. A behavioural test had obvious advantages over a subjective rating scale, in respect of ease of scoring, replicability and possibly a shorter training period being necessary to acquire proficiency in its administration. One disadvantage of the U.E.F.T. lay in its length. Typically one hour might be required to administer it to a hemiplegic having a severe impairment. Accordingly, a series of studies was completed, as described in this thesis, to develop the U.E.F.T. into a measuring instrument of high reliability, valid in the sense of being demonstrably related to competence in activities of daily living, and of relatively briefer duration. The intention was then to use this as a dependent variable to evaluate outcome in EMG. biofeedback treatment of the upper extremity.

Occupational therapeutic approaches

The second major professional group engaged in the functional assessment of hemiplegic patients is that of the occupational therapists. Whereas physio-therapists tend to be interested in motor function per se, the occupational therapist seeks to measure and enhance the hemiplegicpatient's competence in skills involving motor and cognitive components.

One particular contribution of the occupational therapist is in the area of activities of daily living assessment. The format for assessment of A.D.L. frequently differs fron one occupational therapy department to another, according to the needs of the patients and preferences of the departmental staff: however, some published versions have acquired a certain prominence. Since publication of the earliest standard texts on this subject (Buchwald, 1952; Lawton, 1963) a range of alternative A.D.L. tests have appeared, which have differed in the range of activities sampled, their degree of comprehensiveness within a general category of behaviour, and the scoring criteria adopted. Carroll's (1962) version contained twelve items:

	permissible grades			
bowel and bladder control	0		5	10
decubitus ulcer	0		5	
contractures	0		5	
communication	0	3	5	
feeding and personal toilet	0		5	10
dressing	0			10
propel wheelchair	0		5	10
move from bed to wheelchair	0			10
move from wheelchair to bed	0			10
get on and off toilet	0			10
ambulate 100 feet	0		5	10
ascend and descend steps	0			10

Carroll provided no data on the reliability of the scoring system, but did present a classification of patients into six groups, on the basis of A.D.L. scores and as a means of predicting need for nursing

care in an attempt to demonstrate the test's validity. The differentiation between patients afforded by the test was however obviously rather coarse. One positive feature of Carroll's test was that patients were required to attempt the various activities in the presence of the examiner, and were not rated merely on the basis of his recollection of the patient's general level of competence.

Mahoney and Barthel's Barthel Index (1965) used criteria which related to the degree of assistance required by the patient in performing ten common activities of daily living. The activities assessed, although grouped differently than in Carroll's (1962) evaluation, were essentially similar, except that communication, and the presence of decubitus ulcers and contractures were not scored. The maximum score varied between five and fifteen, for independent completion of the activity, while completion with assistance received approximately half the maximum score. Mahoney and Barthel gave explicit criteria to be used in making the assessment, which was intended to be behavioural. Whilst Mahoney and Barthel presented no evidence for the reliability of the measure, the Barthel Index was to an extent validated by Granger, Sherwood and Greer (1977) who found admission Barthel Index scores to be related to prognosis for rehabilitation in stroke patients. The Barthel Index shared the disadvantage of pro-

viding an assessment of a limited range of activities, with Carroll's test mentioned above.

The Kenny Self-Care Evaluation (Schoening and Iversen, 1968), employed a four-point rating scale, to assess six basic self-care activities: bed, transfers, locomotion, dressing, personal hygiene, and feeding. The activities were subdivided into their constituent actions and a score was assigned on the basis of the number of these which the patient could perform unaided. A fifth score point was allocated to performance which could not be otherwise classified. A particular strength of Kenny's study was that serial testing of patients was undertaken to compare curves depicting functional recovery, across self-care activities. This produced interesting data regarding differences between left and right hemiplegics. For instance, right hemiplegics more rapidly recovered competence in personal hygiene activities than did left hemiplegics.

Katz, Downs, Cash & Grotz (1970) using an Index of A.D.L. virtually identical in skill coverage to the Kenny evaluation, but employing a three-point rating scale, drew attention to the sequence in which self-care capability was likely to return. They found that return of independence in feeding and continence preceded acquisition of competence in transfers and toiletting, which in turn preceded recovery of

independence in dressing and bathing, in a mixed group including stroke patients. Katz et al. further produced evidence to demonstrate a statistical relationship between Index of A.D.L. score at discharge and an index of mobility two years later.

Halstead & Hartley (1975) placed emphasis on yet another aspect of assessment of the same six basic areas of self-care examined by the studies reviewed above. Their time care profile sought to quantify dependency by using a diary method to record the frequency and duration of acts of assistance to the patient by care staff. Hence the patient's needs, and their cost to others, might be evaluated. They cited the example of two patients both incontinent, once per day in one case, and twelve times in the other: the latter posed a considerably greater demand on staff time. The importance of distinguishing capability from performance was illustrated by the finding of discrepancies in the same self-care skills as performed at different times of day, due in part to the effects of fatigue. They also argued that tests of A.D.L. frequently elicited an atypically optimal performance from the patient, because of a sense of occasion: hence observation over a period of time was to be preferred. Halstead and Hartley investigated per cent inter-rater agreement on recorded time and frequency of assistive acts for various categories of A.D.L. but

found this to range between thirtyseven and eighty for the former, and fiftyone and ninetyseven for the latter. Data was, however, collected for only five patients.

Lawton and Brody (1969) made the distinction between activities necessary for physical self-maintenance (P.S.M.S.) and instrumental activities of daily living (I.A.D.L.). The P.S.M.S. assessed basic self-care activities such as toilet, feeding, dressing, grooming, ambulation and bathing, whereas the I.A.D.L. was concerned with activities such as use of the telephone, shopping, preparation of meals, housework, laundry, use of transportation, self-administration of medication and financial competence, subdivided into gradations of dependency and scored in yes/no format. Within activity categories, both scales were found to satisfy Guttman scale criteria, when administered to large patient samples ($n = 265$; $n = 168$). Furthermore, inter-rater reliabilities were found to be high, albeit on a substantially reduced sample size (P.S.M.S. $r = + 0.87$, $n = 36$; I.A.D.L. $r = + 0.85$, $n = 12$). The physical self maintenance scale was found to correlate + 0.61 with the instrumental activities of daily living, and each was correlated to a lesser, but yet significant extent, with physical classification, rated mental status, and rated behaviour and adjustment. The differentiation between P.S.M.S. and I.A.D.L. might

allow preselection of the appropriate skill range and thus promote efficiency of assessment.

But the I.A.D.L. was still restricted in breadth of skill coverage by comparison with the A.D.L. of Donaldson, Wagner and Gresham (1973), which was a comprehensive A.D.L. test, adapted for computerisation. From entries relating to the patient's performance on one hundred and fifty variables reflecting competence in fourteen categories of A.D.L., computer programmes had been devised to yield equivalent Kenny, Katz, and Barthel indices from that data base. Data from 100 medical rehabilitation patients allowed a comparison to be made as between these three alternative measures, from which it was concluded that the Kenny self-care evaluation was more sensitive to change than the Katz index, with the Barthel Index being intermediate between the two. The Donaldson A.D.L. evaluation would require an inordinate amount of time, were each item to be administered behaviourally. Accordingly, Donaldson advocated completion of the assessment by staff already familiar with the patient's capabilities, in other words, by recall. Data on inter-rater reliability was not provided. The results of a test-retest study were not reported in sufficient detail to permit the appropriate statistics to be calculated.

An evaluation of activities of daily living must

involve, as has been seen above, some degree of compromise as between rapidity of administration, and density of skill coverage. Constraints upon availability of staff may encourage a preference for rating scales of proficiency in place of actual behavioural tests, but it should not too readily be assumed that assessments obtained in this way are a valid indicator of the patient's competence, although they may range over wide areas of behaviour. The study of A.D.L. reported in this thesis grew out of a need to establish the wider validity of the ARMTEST measure: however, the opportunity was taken to attempt two radical changes in the manner in which A.D.L. might be assessed. In the first place, the grouping of A.D.L. activities by categories such as toileting, feeding, housework, although superficially logically appealing, did not appear to relate to any underlying similarities in the patterns of movement involved. Since it is patterns of movement, and functions such as balance which are commonly impaired in physical disability, and amongst stroke patients in particular, it seemed appropriate to seek statistically identifiable groupings of A.D.L. items which might reflect such an underlying categorisation of disability. Secondly, if such groupings could be identified, it might well be found that their constituent items formed an hierarchy of difficulty, sufficient to constitute a Guttman scale.

It is a property of Guttman scales that successful completion of more difficult items predicts success with items of lesser difficulty; and that failure on easier items predicts failure on the more difficult. If A.D.L. assessment could be so structured, testing time might be considerably truncated without any corresponding loss in comprehensiveness of the range of skills over which prediction could be made. A further advantage accruing from groupings of A.D.L. items reflecting similarities in underlying function might be that corrective therapy, or use of prosthetic devices for a defective movement pattern or function might facilitate performance over a wider range of activities, as compared with the current tendency to teach specific skills in a piecemeal fashion. One consequence of this line of thought was that the use of assistive devices should be incorporated within the A.D.L. assessment, and analysed together with unassisted and personally assisted performance. For reasons of validity, it was further decided that all ratings should be based upon the behaviour of the patient in a behavioural test situation.

Relevance of cognitive factors

The relation of cognitive assessment to the sensorimotor and A.D.L. assessments described above must be considered by a researcher in this area.

Unfortunately, however, the direct applicability of psychological tests in relation to functional use of the limb has not been addressed to any significant extent in the literature. One exception to this was the study by Bourestom and Howard (1968) who found that the Performance IQ of the Wechsler Adult Intelligence Scale, the Porteous Maze Test and Part B of the Trail Making Test each discriminated those hemiplegic patients likely to improve their self-care status during rehabilitation, although each test discriminated at a different level of impairment. However, this finding should not be accepted too readily at face value, since the three tests mentioned require progressively finer degrees of manual dexterity: hence their discriminative power may be mediated by levels of sensorimotor impairment, rather than reflecting underlying degrees of cognitive ability. In further support of this argument, it may be said that WAIS Performance IQ, the Porteous Maze Test and the Trail Making Test all rely heavily on the preservation of upper extremity function, which also figures prominently in the statistically derived scales of A.D.L. function described in a later section of this thesis. That is, upper extremity function may be a primary determinant of the ability to perform A.D.L. Neuropsychologists have unfortunately hitherto tended to concentrate on the

assessment of cognitive function as a form of pure science, or as an aid to diagnosis in neurological disorders, relatively without concern for the ability of their measures to predict coping behaviour in the domestic environment. (Smith, 1975; Walsh, 1978), although there have been exceptions (Broadbent, 1979). One particular problem lies in discriminating between the various input/output disorders, whether visual, sensory, motor or linguistic, and the cognitive, information processing aspects of problem solving. Some tests used by speech therapists, and to a lesser extent by clinical psychologists, in the assessment of aphasia (Eisenson, 1954; Porch, 1967) do seek to discriminate as between varieties of agnosia, aphasia and apraxia, but without attempting to demonstrate their validity in predicting performance of everyday activities.

During development of the Guttman-scaled A.D.L. test described below, the testers were permitted to give verbal instructions, to indicate by gesture and to demonstrate the activity which the patient was required to perform: hence any difficulty experienced by the patient was more readily attributable to the effect of the physical disability itself, or to cognitive deficit affecting the ability to plan and execute an activity or sequence of activities. In addition to providing a scale depicting the relative difficulty caused by restric-

tions of limb function imposed by the illness, it was hoped to identify statistically, cognitive dimensions of A.D.L.. Happily, at least one scale so derived appears to test for degrees of ideational apraxia. Research to establish the validity of neuropsychological assessment procedures as predictors of coping behaviour has been insufficient to date, and might repay detailed study by yielding substantial benefits in improving the effectiveness of current rehabilitative practices. One example might be enhancement of a range of activities by provision of an external prosthetic memory, where apraxic difficulties were evident.

CHAPTER THREE

BIOFEEDBACK

Biofeedback is the term applied to a number of procedures whereby learned control may be established over some bio-electrical response. Typically, electrical correlates of a bodily function were detected and transduced to produce an amplified signal from an external source, which so revealed the state of that function. Learned control acquired in this way was of great theoretical importance in that the distinction between the autonomic and voluntary nervous systems had previously been thought to be reflected in the distinction between classical and operant conditioning. Miller's 1969 paper described several experiments with rats demonstrating changes in heart rate, visceral activity, blood pressure, urinary pH, and peripheral vasomotor responses. Elaborate precautions had been made to eliminate voluntary nervous system activity as a possible mediator of "pure" autonomic learning; animals were typically curarised and artifically respirated, and reinforcement was by brain shock (intracranial stimulation). Despite these precautions, however, Miller and Dworkin (1977) conceded that uncontrolled factors had contributed to the variance in some earlier

experiments, as for example when fluctuating blood CO_2 levels during forced respiration of the curarised animal were found to have affected heart rate. Of additional concern was the difficulty experienced by some workers in replicating Miller's initial findings, even in Miller's own laboratory (Miller & Dworkin, 1974) and the impossibility of excluding CNS mediation since, on Miller's admission, curare blocks neuromuscular functioning when a skeletal pattern is initiated, but not visceral aspects of that pattern. Biofeedback techniques as applied to humans are more fraught with problems of theoretical interpretation than are the animal experiments, and the concern here has been principally to demonstrate an effect, rather than to prove a theoretical point. But even with this limited aim, the extensive review by Blanchard & Young (1974) concluded that findings were equivocal for almost every human application of biofeedback involving functions mediated by the autonomic nervous system, principally because of inadequacies in experimental design. Biofeedback seemed to be in danger of becoming too uncritically accepted as of proven efficacy. There was some puzzling intransitivity too, in that for instance, whilst cardiac acceleration could be rapidly and readily acquired, deceleration

was slower and less easy to accomplish, (Lang & Twentyman, 1976), perhaps reflecting differing underlying physiological processes. The impossibility of eliminating cognitive mediation in some tasks, viz. thermal imagery in temperature regulation, contributed to the theoretical imprecision of biofeedback as seen from a conditioning viewpoint.

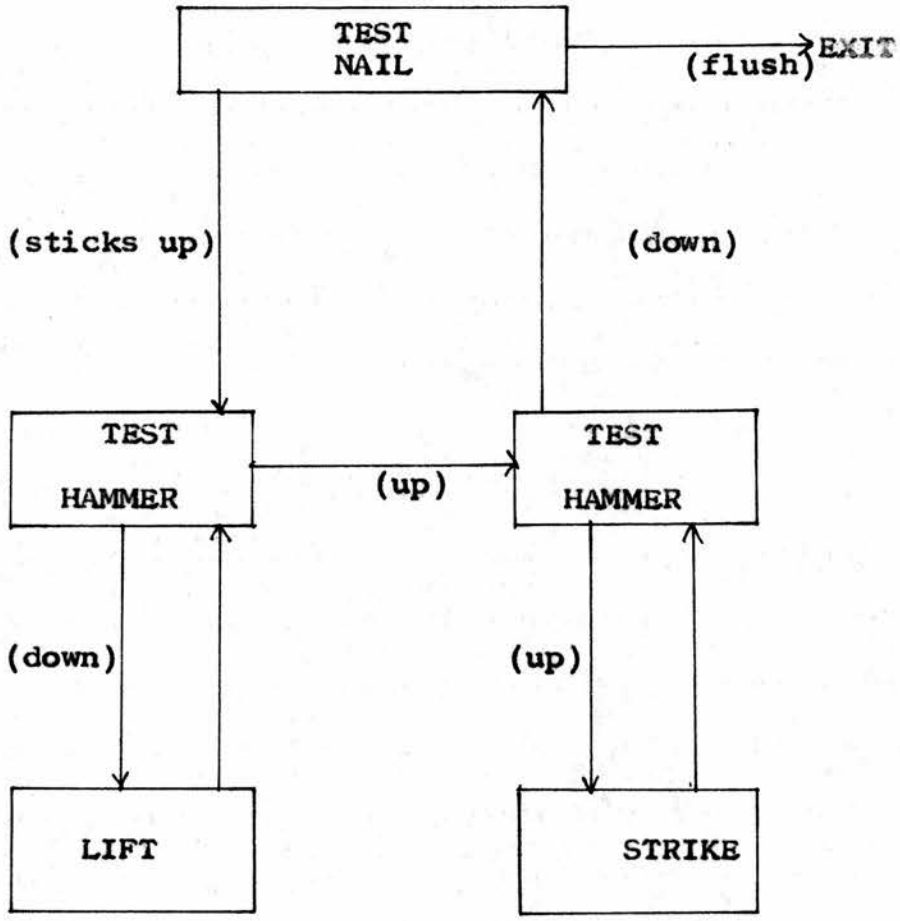
Theoretical explanations of biofeedback effects

Some greater clarity is achieved by the radical behavioural, and the cybernetic, or more recently, information processing approach. In the former (Skinner, 1938) as applied to biofeedback (Black, Cott & Pavloski, 1977) behaviours are capable of being operantly conditioned by use of contingent positive reinforcement. Lack of previous discrimination training is advanced as an explanation for the prior non-emergence of operant control over private bodily processes. Since on this view, no behaviour occurs without reinforcement, then if control has been established, reinforcement is deemed to have occurred (Chomsky, 1959). This is satisfactory, always provided that one can accept the first postulate. Where tangible, e.g. monetary, gain or social approval are programmed or occur naturalistically in the experiment, a reinforcing stimulus can be readily identified; but it is

not self-evident that interaction with a machine should be reinforcing unless one postulates some internalised response. This would appear to conflict with the radical behaviourists' stated aim of constructing an objectively verifiable theory of behaviour (Skinner, 1953).

The term cybernetics was introduced to describe a field of study embracing communication, control and statistical mechanics, whether in machines or in living tissue (Wiener, 1948). The central notion was that of feedback, whereby information about the outcome of a particular sequence of activity was fed back in order to regulate that activity. Negative feedback, which tended to oppose what the system was already doing, was appropriate where the system was designed to oscillate about a mean, as e.g. in homeostasis as related to CO_2 concentration in the blood, or as in a thermostat in a central heating system; while positive feedback, which tended to maximise change in a desired direction, would be appropriate in tasks relating for instance to skill acquisition. The notion of feedback as applied to behaviour was developed by Miller, Galanter & Pribram (1960) into the TOTE unit, TOTE being an acronym for the sequence: Test, Operate, Test, Exit. Miller's schematic diagram to indicate such a sequence relevant to

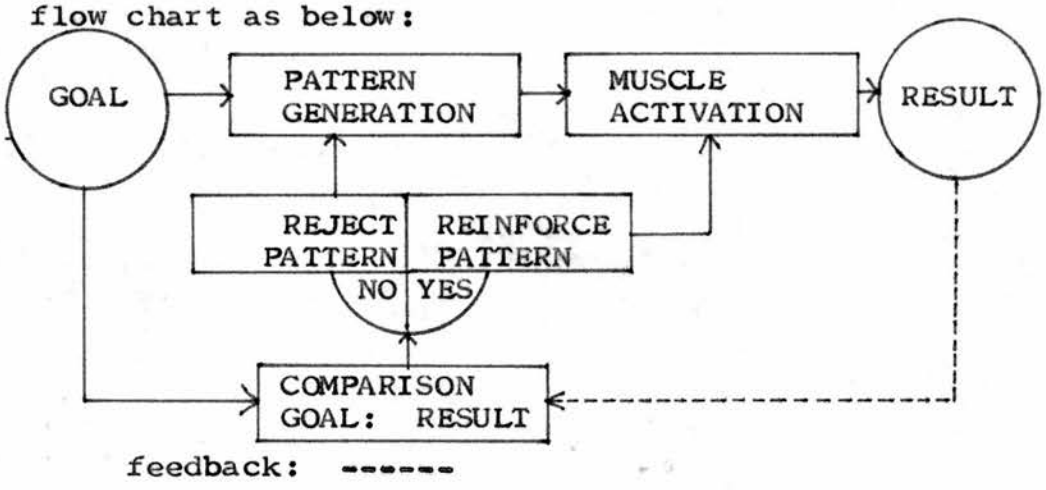
the problem of hammering nails is reproduced below:



From that point onwards, a body of theory in psychology termed "information processing" developed, which interpreted human (and animal) behaviour by analogy with machine, and particularly computer processes. The argument for this manner of proceeding had been provided by Turing (1937). The relevance of Turing's work was that if, after analysing an organism's behaviour, a computing machine could be built, using the principles revealed by that analysis, which would exhibit the same behaviour, then this was a validation of those principles as a model by which to predict that behaviour. One saw, for instance, the development of computer programmes to simulate human problem solving activity (Newell, Shaw & Simon, 1958). Other writers were inspired to construct an entire approach to understanding cognitive functions, using information processing concepts (Neisser, 1967).

Our own approach here is rather less ambitious. In seeking to construct an information processing model of biofeedback, we might conceptualise that the auditory or visual signal provided, externally closed the positive feedback loop, a feedback loop not normally closed since subjective awareness of autonomic activity is low. In the case of biofeedback of E.M.G. with

the hemiplegic, it is possible to imagine that the visual and kinaesthetic feedback normally accompanying voluntary movement has been interrupted (a) because the patient is no longer able to produce discernible movement in the muscles under study; and (b) because proprioception is almost always impaired (Brodal, 1973). Electromyogram feedback, being sensitive to extremely minute variations of myoelectric activity in the microvolt range can thus be used to train increases in muscle activity, until discernible overt movement permits a visual feedback loop to be established. A diagram of hypothetical processes involved in neuromuscular education might be synthesised in the form of a flow chart as below:



feedback: ------

One shortcoming of the above model, as of cognitive psychology, is that it does not account for motivation, and would therefore require to borrow a concept such as reinforcement from learning

theory, or achievement motivation (McClelland, 1961) from social psychology, to account for this aspect of performance.

Clinical applications of biofeedback

As stated earlier, many human applications of biofeedback attempt control over various autonomic functions. The likely clinical application of biofeedback would seem to be particularly to modification of psychosomatic disorders. However, frequently, experiments have been conducted in which baseline measures have been inadequate; in which small numbers of individuals (sometimes not clinically ill) participated; in which adequate control and placebo groups have not been included; in which outcome data have not been presented or statistically analysed; in which outcome measures have been identical with the variable under modification; and in which no follow-up data have been presented (Weiss & Engel, 1971; Gannon & Sternbach, 1971; Benson, Schapiro, Tursky & Schwarz, 1971). The issue of experimental design in biofeedback therefore merits some considerable attention (Barlow, Blanchard, Hayes & Epstein, 1977). The extensive patient contact sometimes necessary dictates a need for ingenious multiple single case designs, systematically replicated, capable of coping with potentially irreversible effects, amenable to statistical analysis, incorporating credible control procedures, and yielding data on clinical response.

In their extensive critical review, Blanchard & Young (1974) excepted one area of application of biofeedback from their verdict of not proven. It is interesting that this related to an aspect of bodily function predominantly under voluntary, as compared to autonomic control: biofeedback of electromyogram (E.M.G.) or striate muscular activity. Feedback of E.M.G. has an obvious application as an aid or as an alternative, to progressive muscular relaxation (Jacobson, 1938) in the treatment of normals or psychoneurotic patients. Malmo (1957) had indeed extensively used E.M.G. data to substantiate his theory of anxiety state as being a disease of over-arousal. Several studies have supported the efficacy of E.M.G. feedback as a treatment for anxiety states, with generalisation from the local muscular response to produce a discernible reduction in anxiety (Raskin, Johnson & Rondestvedt, 1973). A rationale was developed for the use of E.M.G. feedback for frontalis muscle activity as treatment for tension headaches for which it has proven effective (Budzynski, Stoyva & Adler, 1970; Wickramasekera, 1972) although Gray (1977) was unable to demonstrate the superiority of feedback over generalised muscle relaxation training, using a modified Jacobson technique. A further successful area of application was in the elimination of subvocalisation in reading, where

use of E.M.G. feedback to lower throat muscle activity produced an increase in reading speed (Hardyck, Petrinovich & Ellsworth, 1966).

E.M.G. biofeedback with the neurologically impaired

Applications of E.M.G. feedback reviewed thus far have been conducted with neurologically intact patients. The rehabilitation of physically disabled patients by means of neuromuscular re-training using E.M.G. feedback, does however, arguably represent a more stringent test of the efficacy of biofeedback, in that alternative cognitive mediators are not readily available. E.M.G. feedback has been applied to neuromuscular retraining in attempts to gain control over involuntary activity of the skeletal musculature, and conversely to improve or restore the purpose-ful use of the voluntary musculature. The work of Basmajian (1963) demonstrated that a very fine degree of control was possible over a single motor unit and the fibres which it innervated by utilising a combination of visual and auditory feedback of amplified E.M.G. voltage. Typically in such experiments, a process of shaping, as it is called in operant work, is employed whereby the sensitivity of the amplifier is adjusted initially in order to yield a clearly discernible change in the output signal in response to the

most minute variation in E.M.G. voltage. As control is established, the sensitivity of the output or feedback signal, to E.M.G. changes, is diminished, thus requiring a larger variation in the input signal in order to register a discernible change in feedback. Experiments have been conducted in biofeedback utilising variously binary or analogue feedback, visual and/or auditory; however, even passing over the strictures enumerated earlier concerning the inadequacy of experimental design, it is impossible to make a generalisation about the superiority of one method or another, given that the optimal mode might vary according to the experimental task, the type and extent of pathology, or even reflect individual differences (Leaf & Gaarder, 1971). In the absence of definitive proof that one feedback modality is superior to another, some studies in the area of neuromuscular rehabilitation have used both auditory and visual feedback (Andrews, 1964; Johnson & Garton, 1973; Basmajian, Kukulka, Narayan & Takebe, 1975), while others have used auditory (Marinacci & Horande, 1960) or visual feedback only (Booker, Rubow & Coleman, 1969).

The first report of any importance regarding the application of E.M.G. biofeedback to neuromuscular retraining, was by Marinacci & Horande (1960). They provided a number of anecdotal single

case reports describing the application of the technique to upper motor lesion, reversible physiological block, disuse atrophy in causalgia, nerve injury, Bell's palsy, and residual deficit resulting from poliomyelitis. The studies were uncontrolled, but muscle voltages were reported. The procedure used was to insert a needle electrode into the apparently denervated muscle group, and to determine the latent muscle function still present. Auditory feedback was next provided to externally close the feedback loop.

Chronologically the next important experiment was by Andrews (1964) who treated two series of ten hemiplegics, with paralyses of from one to fourteen years' duration, each with a single five minute session. Andrews first inserted needle electrodes into the innervated biceps and or triceps muscles in order to demonstrate the feedback principle, and to acquaint patients with the specific mental effort required. Feedback was provided in both visual and auditory modalities. Electrodes were next inserted into the corresponding denervated upper limb muscle, which was found to show no electrical activity on voluntary effort (Andrews, 1978). Seventeen patients responded to feedback by producing within a five minute period

> "many muscle unit action potentials capable of producing strong, voluntary, controlled action of that muscle".

Of the three patients who failed to respond in this dramatic way, one improved after fifteen minutes further feedback, one was felt to have been insufficiently motivated, and the third was found to have more brain damage than originally suspected. Although Andrew's study was almost totally uncontrolled, in the sense that patients were not randomly selected, and no independent, or standardised measure of limb function was used, that study nevertheless set a mood of optimism perhaps to a greater extent than any other, in neuromuscular rehabilitation of the hemiplegic. The only reported exclusion criteria related to inability to obey simple commands to raise the arm on the non-paralysed side. One is, however, puzzled by the rapidity of the recovery, should some learning process be involved, and also by the strength and co-ordination of the restored muscle function, when one might have expected some atrophy of disuse and even forgetting of motor engrams.

Another area of application for E.M.G. feedback relates to the use of the lower limb. The leg and foot requiring less finely controlled movement for useful function, more rapidly return to semifunctional use in hemiplegics than do the arm and hand (Wahle, 1973). However, hemiplegics frequently require to circumduct the leg and foot on walking in order to avoid stubbing their toe

on the ground. This is because the pattern of hemiplegic contractures is extensor in the leg, meaning that the knee and ankle joints cannot be flexed in the normal way. Johnson & Garton (1973) described a series of patients treated for foot drop, using monopolar needle electrodes for E.M.G. with audiovisual feedback, administered for three, thirty-minute sessions. This was followed by home practice using a portable machine. Motor function was graded on the scale: zero, trace, poor, fair, good and normal. Prior to treatment, only one of eleven patients attained the grade of fair. Post-treatment, seven were grades of fair, two were rated as good, and one as poor. One patient dropped out from the trial. All but one subject improved, including one with expressive aphasia, but this was E.M.G. feedback for the leg and foot only, and some improved only slightly, as e.g. from poor to fair plus, while others did not improve functionally, that is they showed improvement in muscle tone only, as rated on a subjective measure.

Basmajian et al. (1975) published a study incorporating a control group receiving therapeutic exercise as compared with an E.M.G. feedback group treated for foot drop using surface electrodes. Increases in both strength and range of motion were found to be twice as great in the

latter group, but these were significant at the 0.05 level and then only for muscle strength increase, when the data were subjected to statistical analysis (Fish, Mayer & Herman, 1976). From a close reading of Basmajian's paper it was evident that the measures, although quasi-objective, were not taken blind. There were also doubts as to the initial comparability of the two groups of patients.

Takebe & Basmajian (1976) subsequently reported that the subjects in Basmajian's earlier (1975) study showed no significant change in nerve conduction velocity in either the ulnar or peroneal nerve: from which they concluded that whatever enhancement may have occurred in performance, was not directly related to relief of spasticity.

Later studies suggestive of lesser efficacy

Brudny, Korein, Grynbaum, Friedmann, Weinstein, Sachs-Frankel & Belandres (1976) reviewed a rather larger series of fortyfive patients with hemiparesis, thirtynine of whom were treated for upper limb impairment, by means of auditory and visual E.M.G. feedback, using surface electrodes. Gains were measured on a four-point scale and all patients had disabilities of twelve months duration or more. Twenty patients retained "significant" gains for at least a three month follow-

up. But the subjective criteria for improvement, the absence of control treatment and of statistical treatment of the data left grounds for dubiety. One noted, however, the relatively low proportion of improved patients as compared with other studies, and that amongst hemiparetic patients, whom one might reasonably have expected to have had a better prognosis.

Teng, McNeal, Kralj & Waters (1976) reported a series of experiments wherein periods of training with a functional electrical stimulation device of the type pioneered by the Ljubljana group (Gracanin, Kralj & Rebersek, 1970) were alternated with audiovisual feedback of isometric torque from foot dorsiflexion, however, the results obtained were inconsistent even for the small number of patients studied. The Ljubljana functional electrical stimulator itself merits brief description. The device works by tetanising a preselected combination of muscles from among the quadriceps, tibialis, peroneal, gastrocnemius and knee flexors, in synchrony with the swing phase of ambulation. Synchronisation is achieved by activation of microswitches implanted in the heel of the wearer's shoe, which in turn trigger the stimulator via a radio link. Systematic use of this device over periods of a month or more is reported sometimes to result in the recovery

of voluntary, approximately normal gait, on the previously impaired side, for hemiplegics showing foot drop, so that use of the stimulator can be discontinued. This generalisation of training to periods of non-use of the device raises interesting theoretical questions as to the mechanism of recovery. One explanation may be that antidromic responses, generated by pyramidal stimulation may facilitate the establishment of neural pathways. One can thus conceptualise F.E.S. as closing, by artificial means, a motor and a feedback pathway. Luria (1963) has described a treatment technique similar in principle, termed corrective afferent therapy, whereby a discriminable sensory stimulus is applied to the extremity of a paralysed limb as a means of enhancing sensation in that limb, and thus facilitating recovery. It will be evident that the physiotherapy techniques of faradism and short-wave diathermy also contain incidental elements of the practices described above. Unfortunately, no controlled studies of the above techniques have so far appeared in the literature, although a trial of the Ljubljana apparatus is under way in this country. Lee, Hill, Johnston & Smiehorowski (1976) studied the effects of audiovisual E.M.G. feedback applied to strengthening the paretic deltoid muscle in eighteen stroke patients. All patients

underwent periods of true, placebo and no feedback in randomised order. Surface electrodes were used. Treatments, which were administered on three consecutive days, consisted of twenty consecutive contractions of five seconds each, interspersed with rest intervals of ten seconds. This was one of the few studies in which such parameters of treatment were explicitly reported. The peak of rectified and integrated E.M.G. recorded on successive occasions served as the dependent variable. No statistically significant differences were apparent across treatments. Although analysis of variance was not reported, there was a suggestion of an interaction effect of age and motivational level by type of treatment, whereby the E.M.G. trend was <u>incremental</u> over true and no feedback sessions, for the older and more poorly motivated (as rated subjectively) patients; and <u>decremental</u> for the younger and better motivated. The difference in slope of the regression lines was reported as significant, as between these groups, but without reference to baseline E.M.G. levels. The sequential processing of data following disconfirmation of the primary hypothesis, and selective reporting of statistics in this study are however to be deprecated. It was also difficult to generalise from the results of this study in view of the brief duration of the

feedback treatment. Mroczek, Halpern & McHugh (1978) executed a study of nine hemiparetic patients who underwent both physiotherapy and E.M.G. biofeedback treatment of the upper extremity. A crossover design used each subject as his own control, and a baseline was incorporated, albeit of shorter duration than either of the treatments studied. Dependent variables were averaged peak E.M.G. response, and range of movement as recorded by goniometer. Surface electrodes were used for the E.M.G. work, and accurate replication of electrode placement was facilitated by the use of skin dye. Treatment consisted of four weeks of thrice weekly sessions, of unspecified duration. Pooled group analysis showed no significant difference between biofeedback and physiotherapy for E.M.G. activity or range of motion, although both differed significantly from baseline. Incorporation of placebo treatment and a study of the reliability of the range of motion measure, would further have strengthened this quite rigorous experiment. The use of a functional, behavioural measure of improvement was noteworthy. The small number of patients would however seem to contraindicate the use of statistics designed primarily for large scale group comparisons. Wolf, Baker & Kelly (1979) studied a sufficiently large number

of stroke patients to be able to discern patient characteristics associated with a better outcome. The treatment comprised E.M.G. audiovisual feedback, using surface electrodes. Fortyeight upper and fortyfour lower limbs of fiftytwo patients were studied. The age, sex, hemiparetic side, duration of stroke or previous rehabilitation, and number of biofeedback training sessions bore no significant relationship to treatment outcome as assessed by independent rators using a three-point qualitative scale. Failure outcome more often ($p<.005$) resulted, however, when the upper limb was treated. Wolf et al. also claimed to have found that an adverse outcome was more frequent when degrees of proprioceptive loss or aphasia were present; however, statistical analysis of this data was not reported, and when the appropriate statistic, namely Fisher's exact probability test was applied, no significant differences could be found to support this conclusion ($p<.07$). One noteworthy finding from this study was the relatively modest proportion of patients experiencing positive outcome for treatment of the upper extremity.

Conclusions

In their review of clinical applications of biofeedback, Blanchard & Young (1974) concluded

that the evidence supporting the application of E.M.G. feedback in neuromuscular retraining was the strongest available to support any clinical application of biofeedback. Engel-Sittenfeld (1977) and Inglis, Campbell & Donald (1976) more phlegmatically conceded that the technique looked promising. From the review above it is readily apparent that the conclusions drawn by researchers from the results of their studies, should not be accepted without the closest scrutiny of the experimental procedure and the resulting data. In particular, there is conflicting evidence for the likely efficacy of biofeedback training of the upper limb in the hemiplegic. Andrew's (1964) dramatic findings of recovery do not seem to have been mirrored, for instance, in Brudny et al's (1976) or in Wolf et al.'s (1979) results. It would seem desirable again to apply E.M.G. biofeedback to the upper extremity of patients of as long standing and as severely impaired as Andrew's apparently were. It would also seem reasonable to exclude patients immediately post-lesion in order to reduce the likelihood of spontaneous recovery contaminating the results. Within such an experiment it would seem desirable to select patients at random, for distribution as between an experimental group receiving E.M.G. feedback;

a placebo group to control for motivational and attentional aspects of participation in a scientific trial of a novel treatment; and a waiting list group to control for the reactive effects of testing and passage of time: this random allocation being from a pool of patients approximately matched on factors thought relevant to outcome. This would help to prevent the introduction of a systematic bias into the experiment. It would further seem necessary to use objective, or at least standardised, measures of known reliability to assess functional improvement, in lieu of proceeding on the basis of E.M.G. readings alone, since the former does not inevitably accompany recorded increases in E.M.G. levels (Fish et al., 1976). Measures of functional recovery should be taken by independent observers with no knowledge of the particular procedure which the patient has undergone. These precautions would lessen the risk of wishful thinking affecting the results, a particular hazard when ratings are made on the basis of some arbitrarily subjective, rating scale, in place of a standardised behavioural test. The experimental design should suitably reflect the number of subjects participating, as e.g. group designs for large, not small experiments; it should be suited to the procedure under investigation, for example

the use of a reversal of contingencies would be unsuited to procedures from which permanent improvements in function were likely to result; and it should thirdly be capable of generating data which may be analysed statistically, in spite of the recent vogue for relying on descriptive statistics alone in single case methodology (Hersen & Barlow, 1976). Statistical treatment of data is necessary in order to have a basis for establishing the random or non-random nature of a result. Lastly, it would seem prudent to incorporate a follow-up period to determine the duration of any treatment effect observed.

The sequence of studies reported in this thesis sought to clarify previous research by taking account of the methodological considerations outlined above.

CHAPTER FOUR

DEVELOPMENT OF MEASURES: 1

INTRODUCTION

The decision to investigate the effect of treatment upon the upper limb was influenced by three principal considerations. The first of these was the contrasting incidence of recovery in the upper and lower limbs, reported by clinicians. Wahle (1973) found for instance that less than 10% of hemiplegics recovered hand function in full. Linked to that was the relative importance of manipulative tasks in Activities of Daily Living. This was borne out by the correlational study of A.D.L. reported in this thesis, where eight of twelve empirically derived clusters of items, clearly related to aspects of upper limb function. A third consideration was that analysis of gait was and remains problematic, in that some simple reliable standardised and quantitative method has yet to be found of analysing lower limb function under dynamic conditions (Goodkin and Diller, 1973; Takebe and Basmajian, 1976; Dubo, Peat, Winter, Quanbury, Hobson, Steinke & Reimer, 1976).

In view of the poverty of available measures of upper limb function, as reviewed in an earlier chapter, the necessity to develop reliable measures prior to proceeding with the treatment evaluation, was

recognised. At this stage, it was necessary also to decide which aspects of the upper limb should be assessed. Given the constraints on time available, and since the intention was to proceed to evaluate treatment, and not merely to develop tests, the decision was made deliberately to ignore sensory perception and to concentrate on developing a test of function for the upper limb. This was not to deny the possible importance of sensory awareness in the upper limb both as a prognostic indicator (Wolf et al., 1979) and conceivably as a correlate, even a mediator of recovery of function. In selecting a measure of limb function, at least two aspects required to be considered. On the one hand, a measure should provide a sensitive measure of the likely change in function, expected as a result of the treatment. In this regard, the measures reviewed as under "Physiotherapeutic approaches" in the preceding chapter were relevant. Secondly, it was prudent to consider the wider relationship of an increased score on any such specific measure, to enhanced competence in conducting everyday activities of daily living: which must be the ultimate test of the value of the treatment. In view of the comparatively longer time required to administer a test of A.D.L. which would render serial repetition extraordinarily costly in time, it was decided to rely upon correlational evidence to establish the wider validity of the specific limb function measures to be administered during treatment evaluation.

The choice of the specific measures to be employed was guided by a desire to achieve a substantial standardisation of test conditions, and to distinguish between different aspects of upper limb function. The measures had to be sufficiently brief for serial administration to patients at various stages of treatment, and to require little specific training or previous experience on the part of the examiners using them. This latter proviso was made because assessment of patient performance was to be made blind, and it was feared that occupational therapy and physiotherapy staff at the hospital would be too familiar with aspects of the patient's condition and treatment to serve as truly independent examiners: this in addition to consideration of their restricted availability for this task in a hard-pressed service department.

The Upper Extremity Function Test of Carroll (1965) appeared to satisfy requirements, although there was felt to be considerable scope for further abbreviation of the test, which was tedious to administer to patients with dense hemiplegia, since all items had to be administered. It was also desired to obtain further information regarding the inter-rater and test-retest reliability of that test. Carroll's test contained thirty-three items, each to be attempted using standard apparatus with either hand. These items were grouped under the headings: Grasp, Grip, Lateral Prehension, Pinch, Placing, Pronation and Supination, and Writing. On

careful inspection, however, it was evident that certain items measured more than the one function under which they were grouped: test item 26, "iron to shelf", for instance, required a grip strong enough to lift a 2.7 Kg weight, and arm and shoulder movement to raise this approximately 15 inches, and yet was grouped with placing a washer over a nail (item 25); test item 30, "place hand on top of head" required movement of the upper limb both at the shoulder and elbow, in addition to wrist pronation, under which it was classified. Neither was it self-evident that twelve test items should be devoted to various finger to thumb opposition movements using ball-bearings graded 4 mm, 6 mm, and 11 mm: that is, the balance of items composing the test appeared distorted, and some items might be redundant.

A re-standardisation of the U.E.F.T. would represent an opportunity to try to resolve these problems. For instance, test-retest and inter-rater reliability could be ascertained. The data collected could be analysed by correlation to detect clusters of test items, reflecting underlying similarities of function. Correlational analysis would also aid in identifying redundant items, or items unrelated to any other. If items could be arranged into one or more unidimensional scales, then it might be possible to arrange items within such a scale, in hierarchical order of difficulty, in such a way that success on difficult items would predict success also on those of

lesser difficulty. Similarly, failure on easier items within a scale might predict failure also on the more difficult. The statistical procedure which performs this function is Guttman Scale or Scalogram Analysis (Guttman, 1941; Goodenough, 1944). A subprogram for performing this analysis is available in the Statistical Package for the Social Sciences (Nie, Hull, Jenkins, Steinbrenner & Bent, 1975): however, the selection of items to be so scaled, and of cutting scores for these items, is at the researcher's discretion.

Since Carroll's U.E.F.T. required qualitative judgement of the facility with which each item has been performed, it seemed desirable to include in an assessment battery some objective measures currently used in physiotherapy, such as a dynamometer to measure muscular strength and a goniometer to measure range of movement. The pursuit rotor, a laboratory measure of psychomotor speed, was also included.

METHOD

SUBJECTS

Twenty patients attending either the Occupational Therapy Department, or the Astley Ainslie Hospital, Edinburgh or the Simon Square Day Centre, Edinburgh, participated in the study. All had sustained cortical damage, whether as a result of stroke, road traffic or industrial accident, assault, or surgery for aneurysm or haematoma. All had hemiplegia involving the upper limb,

with a duration ranging from 42 years to 1 month, mean 46 months. The age range was 72 years to 26 years, mean 53.2 years, thirteen being male and seven female. Of the twenty patients tested, all but one had been right-handed prior to sustaining their impairment. Exactly half of the patients, including the last-mentioned, were impaired for the non-dominant limb.

MATERIALS AND PROCEDURE

(a) Objective Measures

Two types of dynamometer, both manufactured by Rank Stanley Cox, were used. The first was a grip dynamometer, to be held in the palm of the hand and squeezed. This yielded a reading in pounds of the force exerted. The average of three attempts was taken, separately for each hand. The second was an Isodyne isometric dynamometer. This apparatus consists of a torsion bar to the end of which can be attached a D-shaped handle, or a lever arm with adjustable right-angled handgrip. When a preset torsional force is exerted on the bar, a circuit is completed and a light is illuminated. The Isodyne measurements were taken in two positions. In the first, the patient's elbow rested on the table, whilst the hand, palm uppermost, grasped the handle attached at right angles to the lever arm, and parallel to the longitudinal axis of the torsion bar. The Isodyne was clamped to a wall-mounted rail, and could be adjusted to ensure that the torsion bar was aligned with the patient's elbow. The patient, seated on a chair and at

the table, was asked first to flex, then to extend his arm against the torsion bar whilst maintaining his elbow stationary and in contact with the table surface. This measure was taken for each arm, separately for flexion and extension, and the scale readings recorded. The second task required the patient to grip a D-shaped handle, mounted longitudinally on the torsion bar, and to attempt to rotate the handle from a vertical position, first in a clockwise, then in an anticlock-wise direction using pronation and supination of the wrist. This task was performed with each hand in turn. The goniometer was an optical type, consisting of a plastic lens, incorporating a 360^{o} protractor at its circumference. A rotating cursor pivoted around the central point to measure range of movement at limb joints. The user looked through the lens at the joint, and aligned a zero mark with the proximal part of the limb, then rotated the cursor to align with the distal part. The movements assessed were (1) abduct extended arm to horizontal (2) elbow extension and (3) raise arm forward to horizontal. A maximum reading was set, representing a range of movement which ought to be readily attainable by any normal upper limb. This was ninety degrees for (1) and (3), and one hundred and eighty degrees for (2). The range of movement in degrees was read off opposite the cursor line. The rather ill-fated pursuit rotor had previously been manufactured in a workshop. It consisted of a turntable made of non-conductive material

which could be regulated to rotate as speeds between one revolution per second, and one revolution per ten seconds. Three concentric metal rings, placed eccentrically on the turntable, were the target, and duration of contact between each of these and a hand-held stylus could be scored independently in tenths of a second. Unfortunately, problems were experienced with poor electrical contact between the stylus and target, and with downward stylus pressure slowing the speed of rotation, and use of this apparatus had to be abandoned early in the patient series.

Each patient was seen on two occasions by a team comprising a rater who both administered the various items and rated the patient's performance, and a scorer who independently scored the same performance. All were Clinical Psychologists working in the Edinburgh area. Two such independent teams were used, and each patient was tested once by each team. The test-retest interval had a mean of 7.5 days, standard deviation 6.5 days. Scorers and raters were given brief training in the administration and scoring of the test, the scorers observing and scoring three practice patients, with the raters in addition administering two tests under supervision. All assessments were made independently. Both upper limbs were tested for each patient, following which the objective measures were taken. Preliminary evaluation of results after ten cases indicated that the correlation between scorers' and raters' ratings for the same session was so high (+0.99) both for the

U.E.F.T. and for the objective measures that patients 11 to 20 were seen by the two raters only.

(b) Carroll Upper Extremity Function Test

An attempt was made to duplicate as closely as possible the test materials used by Carroll in his earlier study, given certain constraints on the local availability of materials, and incorporating some simplification. The basic apparatus consisted of a metal trolley, 92 cm x 45 cm x 83 cm high, constructed of angle iron, and with a shelf 93 cm x 10 cm, 37 cm above the main surface of the trolley. Wooden cubes, a cricket ball, three sizes of ball bearing, a marble, a sharpening stone, and a 2.7 Kg iron, all had to be lifted from the trolley surface to the shelf above it. Other test items required the moving of pieces of metal tubing from one location to another on the table surface, the placing of a washer over a bolt, and gross movements of the arm. A plan view and side elevation of the trolley (not to scale) are included in the Appendix, and a table of test items and a test proforma appear in Tables IV(1) and (2). It was decided to dispense with Carroll's item 33, namely, that the patient should attempt to write his own name. This was because of anticipated difficulty in scoring this item, and also to avoid the effect of previous practice. A further deviation from Carroll's original test, was that the use of precise starting locations for each task item was dispensed with: this was because some patients had left, and others right hemiplegia, and test items

TABLE IV(1) - TEST MATERIALS

Item No.	Description	Approximate Dimensions
1	Wood Block	10 cm^3
2	" "	7.5 cm^3
3	" "	5 cm^3
4	" "	2.5 cm^3
5	Metal Tube (light alloy)	2.25 cm diameter x 11.5 cm
6	" " " "	1 cm diameter x 16 cm
7	Sharpening Stone	10 cm x 1 cm
8	Cricket Ball	7.5 cm diameter
9,10,11,12	Marble	1.5 cm "
9,24,25	Tobacco Tin & Lid	10 cm "
13,14,15,16	Ball Bearing	11 mm
17,18,19,20	" "	6 mm
21,22,23,24	" "	4 mm
25	Steel Washer	3.5 cm diameter
26	Smoothing Iron	Weight 2.72 Kg.
27	Plastic Water Pitcher	17 cm x 10 cm
27,28,29	2 Plastic Tumblers	11 cm x 6 cm

TABLE IV(2)

CARROLL - UPPER EXTREMITY FUNCTION TEST (U.E.F.T.)

Patient ..... Date .....

Tester .....

Scoring - 3 - Performs test normally

2 - Completes test but takes abnormally long time or has great difficulty

1 - Performs test partially

0 - Can perform no part of test

Basic Function	Grade Right	Left
GRASP		
1. Block 10 cm^3		
2. Block 7.5 cm^3		
3. Block 5 cm^3		
4. Block 2.5 cm^3		
GRIP		
5. Tube 2.25 cm x 11.5 cm		
6. Tube 1 cm x 16 cm		
LATERAL PREHENSION		
7. Stone 10 cm x 2.5 cm x 1 cm		
PINCH		
8. Ball 7.5 cm		

	Grade	
	Right	Left
Marble 1.5 cm		
9. Index finger and thumb		
10. Middle finger and thumb		
11. Ring finger and thumb		
12. Small finger and thumb		
Ball bearing 11 mm		
13. Index finger and thumb		
14. Middle finger and thumb		
15. Ring finger and thumb		
16. Small finger and thumb		
Ball bearing 6 mm		
17. Index finger and thumb		
18. Middle finger and thumb		
19. Ring finger and thumb		
20. Small finger and thumb		
Ball bearing 4 mm		
21. Index finger and thumb		
22. Middle finger and thumb		
23. Ring finger and thumb		
24. Small finger and thumb		
PLACING		
25. Washer over nail		
26. Iron to shelf		
SUPINATION AND PRONATION		
27. Pour water from pitcher to glass		
28. Pour water from glass to glass (Pronation)		

	Grade	
	Right	Left
29. Pour water back to first glass (Supination)		
30. Place hand behind head		
31. Place hand on top of head		
32. Hand to mouth		

were placed appropriately for the side being tested. Throughout testing the subject sat on a chair 44 cm above floor level, the trolley being close to his/her chest.

RESULTS

I Reliability Study

(a) Objective measures

Although the inter-rater reliability of the objective measures was found to be high, the test-retest reliability in every case fell below that of the U.E.F.T. (Table IV(3)). This is the opposite result to that which might have been anticipated, since the U.E.F.T., although it is standardised, nevertheless requires some subjective judgement on the part of the examiner.

In the case of the Isodyne, it became evident that the expedient of maintaining elbow to table contact had not been successful in isolating biceps/triceps involvement. Many patients locked their elbow joint, and used shoulder movements. Patients with spastic hemiplegia often could not have their arm put into position on the apparatus, and hence no meaningful reading could be taken. It is interesting to note that the Isodyne, originally intended for use as a therapy monitor, or as a form of graded exercise itself, has since ceased to be produced. This perhaps reflects similar difficulties experienced by physiotherapists in attempting to use the apparatus.

TABLE IV(3)

Reliability of Objective Measures (N=20)

	Impaired limb	Unimpaired limb
Isodyne isometric dynamometer	0.67	0.78
Grip dynamometer	0.94	0.94
Optical goniometer	0.90	0.99
Pursuit rotor	0.96	0.97

All Pearson correlations significant at $p < 0.01$ (two-tailed test).

The grip dynamometer, although yielding a satisfactorily high test-retest reliability at this stage, did, however, develop a fault during treatment evaluation, when some free movement was discovered at the scale pointer, which was found to be independent of the rack-and-pinion mechanism; and readings already taken had to be discarded as being of dubious validity. In addition, whilst grip strength might be a correlate of recovery of function with the flaccid hemiplegic limb, it became clear that this was not necessarily so for the spastic hemiplegic limb, where the patient might find difficulty in releasing a strong grip.

The optical goniometer achieved a satisfactory test-retest reliability, although the very high correlation for the unimpaired limb is probably spurious, being due to the maximum permissible score in degrees being well within normal capability. Although this apparatus did not fail in use, following treatment evaluation by an independent rater it became evident in retrospect that the rater felt he had not fully mastered the use of the instrument, and although these measures are reported for the first biofeedback experiment, they should be interpreted with caution.

One worrisome aspect of the findings regarding these "objective measures" was the astonishing opportunity for instrument or user error. It seems difficult to believe that some of the measurement error noted here, has not been experienced or noticed, by others working in this area, perhaps in the remedial

professions. These findings were unexpected, but, in the light of hindsight, might conceivably have been foreseen. They do, however, emphasise the need for reliable and valid measures of limb function for use in assessment, and in the evaluation of therapies. The U.E.F.T. findings compare very favourably with these measures.

(b) Upper Extremity Function Test

The product moment correlation between the two examiners' ratings of the same patient was calculated separately for the impaired and the unimpaired side. This calculation yielded the test-retest reliability, and value obtained was +0.98 in both cases ($p < 0.001$). These results therefore confirmed Carroll's impression of close test-retest agreement. The test-retest reliabilities, calculated separately for the sub-test totals, by Pearson product-moment correlation, are depicted in Table IV(4). It can be seen that these are uniformly impressively high, and sufficiently so to justify their use in monitoring response to therapy.

II Further analysis of the U.E.F.T.

As stated earlier, it was considered that there might be some considerable scope for abbreviation of the U.E.F.T., as by employing Guttman scale analysis; and secondly that the groupings of items evident in the Carroll subscales did not seem in every case to have as their basis an underlying unity of function. The calculation of inter-item consistency, that is, a correlation matrix depicting the relationship of each

TABLE IV(4)

Test-Retest Reliability of the U.E.F.T.

	GRASP	GRIP	LATERAL PREHENSION	PINCH	PLACING	SUPINATION PRONATION
IMPAIRED LIMB	0.95	0.91	0.89	0.99	0.89	0.92
UNIMPAIRED LIMB	CN	CN	CN	0.97	0.52*	CN

CN: Pearson correlation could not be calculated

* : $p<0.02$

All other correlations significant at $p<0.001$ (two-tailed test)

item with every other was a first step towards a solution of both questions. The correlation matrix of 32 x 32 items was computed by the Pearson product-moment method, using minor adaptations to a pre-existing programme on the Edinburgh Multi-Access System. Since the inter-correlation of the different examiners' assessments of the same patients was high (r = +0.98) the data from the first examiner only was analysed as being representative of both. It was decided to correlate data for the impaired limb only, since the majority of patients attained maximum scores on all subtests when using the unimpaired limb: this could have resulted in spuriously high or even incalculable correlations, as when division by zero occurred. The resulting complete correlation matrix, and tabulations of intercorrelations between constituent items for each U.E.F.T. subscale are presented in the Appendix. It is evident from examination of these that certain scales do not have uniformly high inter-item consistency (Pinch, Placing, Supination and Pronation). In addition, some items have manifestly not been placed in the scale to which they bear the closest statistical relationship (items 7, 8; item 25, 28). Adopting a heuristic criterion of a correlation of approximately +0.90, and mindful of the likelihood of some high, chance correlations in the matrix, the data was next scanned in order to detect clusters of correlated items which might form unidimensional, functional scales with an inherently hierarchical order of difficulty. Certain items were

eliminated, in the light of experience gained in testing on the grounds of excessive difficulty (items 12, 20, 21, 22, 23, 24, 26) or of hazard in testing (items 26, 27); because of low inter-correlation with other test items (item 26), or conversely as being sufficiently correlated with other items in an already large cluster as to be redundant (items 13, 14, 15, 16). By trial and error, various combinations of the remaining items were submitted to scalogram analysis using the Guttman scale subprogram of the Statistical Package for the Social Sciences (Nie et al., 1975).

The Guttman scale, named after its originator, Louis Guttman (1941), requires the fulfilment of some very stringent conditions by the data set. The primary requirements are those of unidimensionality and hierarchical scalability. The meaning of the first of these is readily understood. Unless all test items in the proposed scale measure the same attribute, it is futile to attempt to predict performance on some items on the basis of knowledge about performance on others. The degree of intercorrelation between scale items gives some indication of unidimensionality, although this is not an infallible guide; since a high correlation might be fortuitous or specific to the limited population under study. Thus it is important not only to know the inter-item consistency and the part:whole or item:scale correlation: a cross validation is a helpful guide in deciding whether test items do constitute a genuine

Guttman scale. The Guttman scale sub program of S.P.S.S. provides for the computation of inter:item and scale:item correlations using Yule's Q, as an aid in determining unidimensionality. The latter precaution referred to above, namely, cross-validation on a different sample than that from which the original scales were derived, is reported later, having been made possible by the discovery of a complete set of data on fifty patients collected previously by Carroll(1965a) using the U.E.F.T. The second stringent requirement referred to above, is hierarchical scalability or cumulativeness. Each item in a Guttman Scale must be ordinal to the extent of performance being divisible into a pass or a fail. In the case of an item where performance is graded on an n-point scale, a cutting score may be specified, so that a score equalling or exceeding that cutting point is considered as a pass. The Guttman scale requires the provision of such a pass-fail criterion. The constituent items must also possess the capability of being ordered from most difficult to least difficult. If there were no gradation of difficulty, and all items in a scale were uniformly difficult and unidimensional, then all constituent items except for one would simply be redundant from the aspect of prediction. However, if Guttman scale requirements are satisfied, then a pass on the most difficult scale item predicts passes on all other constituent items. Conversely, failure on the least difficult predicts

failure on items of greater difficulty. It is readily apparent that from a Guttman scaled version of Carroll's U.E.F.T. there would accrue potentially considerable savings in testing time, without any corresponding loss in the comprehensiveness of the range of activities sampled. The S.P.S.S. Guttman scale sub program provides for the calculation of certain statistics which aid the researcher in determining whether a given group of test items fulfils this latter criterion of hierarchical scalability. The coefficient of scalability is obtained by subtracting from unity the result of dividing the total number of errors (items passed which should have been failed, and items failed which should have been passed, were the scale perfectly hierarchical) by the total number of responses. A coefficient of 0.9 or above is generally regarded as indicating a valid Guttman scale. The minimum marginal reproducibility represents the minimum value which the above could have obtained; and the difference between these, termed the per cent improvement, when divided by unity minus the minimum marginal reproducibility, yields a coefficient of scalability. The coefficient of scalability is held to indicate a truly unidimensional and cumulative Guttman scale when it is found to exceed 0.6 (Nie et al., 1975).

Using S.P.S.S. to indicate the validity of a possible combination of U.E.F.T. items as consti-

tuting a true Guttman scale, four subscales were eventually identified, each fulfilling internally the necessary statistical criteria. Following inspection of constituent items, these subscales were labelled Grasp, Grip, Pinch and Gross Movement (Gross Mt).

For the purposes of computation, the data for both the impaired and the unimpaired limbs were pooled, and in addition, the ratings made by both of the examiners were pooled. The coefficients of reproducibility and of scalability for the Guttman scales so constructed are depicted in the Appendix, together with their constituent items. At this stage, a further cross-validation was contemplated, when it was fortuitously discovered that Carroll (1965a) had already published raw data from the impaired upper limb of a further fifty patients, representing a far wider spread of diagnosis, and including for example amputees and patients with arthritic impairments. This data was used to cross-validate the Guttman scales already derived from the Edinburgh data. These were found to apply slightly less well, to this pre-existing data set. The relevant statistics are depicted in the Appendix.

Since it had now been demonstrated that the Guttman scaled test survived cross-validation, the next step was to construct a step-wise manner of administering the various test items, in order to take advantage of the inherent hierarchical nature

of the scales. This would eliminate the need to administer every item in each subscale of the test, since an individual scoring three for the most difficult item, would reliably pass all others within that subscale, using the same upper limb. Conversely, an individual scoring zero for the least difficult item, would reliably score zero on all other subscale items. In order to facilitate comprehension by an inexperienced examiner, it was decided to give instructions that the most difficult item in each subscale should be administered first. If the patient obtained the maximum score on this item he could safely be predicted to be capable of obtaining a maximum score on all items of lesser difficulty in that subscale, for the upper limb tested, without further examination. Otherwise, the least difficult item was next to be administered. If a score of zero were to be obtained here, the patient could safely be predicted to be incapable of achieving a total score above zero, and further testing on that subscale could be discontinued. Should the patient's score be bracketed as less than maximum and greater than zero, the remainder of the subscale items should next be administered. This procedure was to be followed for each subscale and upper limb in turn. The Guttman scaled U.E.F.T., named the Action Research Armtest (A.R.A.), together with administration instructions, is depicted in Table IV(5).

A computer programme was next devised in the

TABLE IV(5)

The Action Research Armtest

Patient ..... Date .....

Examiner ..... Side Impaired .....

Scoring: 3: Performs test normally

2: Completes test, but takes abnormally long time or has great difficulty

1: Performs test partially

0: Can perform no part of test

Instructions to Examiner:

Armtest has been specially constructed to speed up testing time. It is divided into 4 Subtests (Grasp, Grip, Pinch, Grossmt). Items within each Subtest are ordered in such a way that if the patient scores three (3) on item one, (the most difficult) he would almost certainly score three (3) on all other items in that Subtest, involving the same side. Thus, if a score of 3 is obtained on item one, the patient is credited with having scored 3 on all items of the Subtest for that (left or right) side, without having to be tested on the remaining Subtest items.

If the patient scores less than 3 on item one, then item two is administered. Item two is the easiest item in each Subtest, and if the patient scores zero (0) then he is unlikely to achieve a score above zero on any item in the Subtest for that side (left or right) on which a zero (0) score was obtained. Thus he is credited with a zero (0) Subtest Total score for that side, and you should move to the next Subtest.

If however, the patient scores less than 3 (3) on item one and more than zero (0) on item two, all items in the Subtest must be administered.

This sounds complicated to explain, but it is easy in practice (reminders are included in the test itself). The result is an average saving of 50% in testing time.

Subtest Grasp

	Side Left	Side Right
1. Block 10 cm (If score = 3, total = 18 and →GRIP)		
2. Block 2.5 cm (If score = 0, total = 0 and →GRIP)		
3. Block 5 cm		
4. Block 7.5 cm		
5. Ball 7.5 cm		
6. Stone		
TOTAL	Left = ____	Right = ____

Subtest Grip

	Side Left	Side Right
1. Pour water glass to glass (pronation) (If score = 3, total = 12 and →PINCH)		
2. Tube 2.25 cm (If score = 0, total = 0 and →PINCH)		
3. Tube 1 cm		
4. Washer over bolt		
TOTAL	Left = ____	Right = ____

Subtest Pinch

Side
Left Right

1. Ball bearing, 6 mm, 3rd finger and thumb (If score = 3, total = 18 and GROSSMT.)

2. Marble 1st finger and thumb (If score = 0, total = 0 and GROSSMT.)

3. Ball bearing 2nd finger and thumb

4. Ball bearing 1st finger and thumb

5. Marble 3rd finger and thumb

6. Marble 2nd finger and thumb

TOTAL Left = ____ Right = ____

Subtest Grossmt.

1. & 2. Place hand behind head (If score = 3, total = 9 or if score = 0, total = 0)

3. Place hand on top of head

4. Hand to mouth

TOTAL Left = ____ Right = ____

Summary

Grasp		Grip		Pinch		Grossmt.		Total	
Left	Right	Left	Right	Left	Right	Left	Right	Left	Right

programming language IMP, in order to simulate running each patient in turn through the Guttman scaled Armtest, to compare the savings likely to accrue in terms of test items not requiring to be administered, as compared firstly with the Carroll U.E.F.T., and secondly with the Armtest without using the hierarchical method of test administration. The Pearson correlations between the three total scores so obtained were also calculated (Table IV(6)). It can be seen that the four subtests of A.R.A. measure different aspects of upper limb function. To what extent may these be inter-related, and what is their relation to the total A.R.A. score? To answer this question, the correlation of each subtest score with every other, and with total A.R.A. score was computed, for the impaired and for the unimpaired limb, using data from the original twenty patients. The resulting product moment correlation matrix is presented in Table IV(7).

TABLE IV(6)

Savings and intercorrelations arising from a comparison of the U.E.F.T., with the A.R.A., with and without hierarchical test administration

SAMPLE	N	U.E.F.T.: HIERARCHICAL A.R.A.	SAVING (ITEMS)
Examiner 1			
Impaired limb	20	0.97	71%
Unimpaired limb	20		87%
Examiner 2			
Impaired limb	20	0.99	67%
Unimpaired limb	20		85%
Cross-validation			
Impaired limb	50	0.97	64%

SAMPLE	N	A.R.A.: HIERARCHICAL A.R.A.	SAVING (ITEMS)
Examiner 1			
Impaired limb	20	0.99	51%
Unimpaired limb	20		78%
Examiner 2			
Impaired limb	20	1.00	44%
Unimpaired limb	20		75%
Cross-validation			
Impaired limb	50	0.99	40%

All Pearson correlations significant at $p < 0.001$ (two-tailed test).

TABLE IV(7)

Correlation of Component Subtests of Armtest (A.R.A.)

1. Impaired side

	Grasp	Grip	Pinch	Grossmt.	Total
Grasp		0.8742	0.7077	0.8885	0.9542
Grip			0.7593	0.8089	0.9415
Pinch				0.5896*	0.8578
Grossmt.					0.8826
Total					

* : significant at $p<0.01$ (two-tailed test)

All other Pearson correlations significant at $p<0.001$.

2. Unimpaired side

	Grasp	Grip	Pinch	Grossmt.	Total
Grasp		CN	CN	CN	CN
Grip			CN	CN	CN
Pinch				CN	1.00
Grossmt.					CN
Total					

CN: correlation could not be computed.

DISCUSSION

At this point, it is necessary to pause to consider the composition of the Armtest subscales, their relationship to each other, and their contribution to the total score. The first subtest, GRASP, comprises the grasp subscale of Carroll's U.E.F.T., but includes also the solitary lateral prehension item 7, and the cricket ball item 8 which was previously grouped with finger-thumb opposition tasks. This re-grouping was chosen on the basis of correlational evidence, and reflects a similarity in the way in which patients functionally achieve these items, that is, by open-handed grasp. A feature not evident at a cursory glance, is that the subtest items constitute two main components. The item must first be grasped, and secondly raised to the shelf positioned 37 cm. above the trolley. A score of one is assigned if the patient can grasp the item, but cannot raise it because the necessary upper arm and shoulder function has been impaired. As can be seen from the statistical data relating to Guttman scale analysis contained in the Appendix, GRASP forms a valid Guttman scale when a division point of 1 is selected. Hence, the scale is really two scales in one, with one Guttman scale comprehended within another Guttman scale. The same is also true for subtest PINCH. Subtest GRIP shares elements in common with GRASP, except that some degree of mobility of

the wrist is required, including flexion/extension and pronation/supination. Subtest PINCH is a test of finger-thumb opposition, comprehended within a test of upper arm and shoulder function. The subtest has been shorn of the redundant and the ridiculously difficult items contained in Carroll's U.E.F.T. subtest. For example, to pinch a 4 mm ball bearing between the thumb and small finger requires a virtuoso performance from an individual with normal upper extremity function. The subtest GROSSMT. requires preservation of some degree of upper arm and shoulder function. A maximum score on item 1 of GROSSMT. requires substantial recovery of function in the hemiparetic limb. Indeed, GROSSMT. and PINCH, usually the first and last aspects of upper limb function to recover in hemiplegics (Twitchell, 1951) are the least correlated.

The pattern of intercorrelations for the impaired limb indicated that the constituent tests correlated sufficiently with the total score to justify their inclusion in a unitary total score. At the same time, scores obtained on the various subtests were significantly intercorrelated, but not so highly as to indicate redundancy. The fact that subtest scores for the impaired limb intercorrelated may be taken to indicate that recovery of function in the hemiplegic limb takes place on a wide front, encompassing many functions.

The findings for the unimpaired limb are obscured by a ceiling effect, in that most patients could

complete each item at the maximum score level, and in most cases, the correlation coefficient could not be calculated.

The savings in test administration accruing from the Guttman scaling exercise are impressive, and yield results almost identical to administration of Carroll's entire U.E.F.T.. The savings are especially high with totally functional and completely non-functional limbs. It is in addition particularly gratifying that the Guttman structure survived a cross-validation using a wider diagnostic group of patients, indicating that it is robust, and suggesting possible future use with other patient populations including amputees, arthritis sufferers, and patients with muscular disorders. The findings on the test-retest reliability of the Armtest are reassuringly high, particularly so in view of the difficulties encountered with the "objective measures" studied and sufficiently so to merit use of Armtest as a measure, repeated serially, of functional recovery in treatment. The use of a dependent variable, other than the specific variable under modification (E.M.G.), seems prudent in this regard: this in order to demonstrate the generalisation of any treatment effect to functional use of the limb.

The Armtest having been developed specifically as a scientific measure of upper limb function for use in assessing biofeedback treatment of the upper limb, does also have potential for use in assessing

many physiotherapy techniques currently employed in rehabilitation of upper limb impairment, extending perhaps beyond hemiplegia only. Some of these techniques (passive movements, proprioceptive neuromuscular rehabilitation) have never been validated in a sufficiently rigorous way to exclude placebo and experimenter effects, let alone measurement error. Hence Armtest is seen as a contribution towards a wider area of research in rehabilitation rather than only the relatively restricted role originally envisaged in this programme of research.

It may be objected that the relationship of Armtest to competency in executing Activities of Daily Living has not been demonstrated. If the reader will forbear, research will be presented in the following chapter to demonstrate that not only does Armtest intercorrelate with A.D.L.: empirically derived clusters of A.D.L. items appear to consist substantially of scales describing upper extremity function. Thus the importance of concentrating on ways of enhancing the return of upper extremity function in hemiplegics is yet further underlined.

CONCLUSIONS

The results demonstrated the unreliability, in both mechanical and measurement terms, of the several "objective" measures studied. Conversely, Carroll's Upper Extremity Function Test, although requiring several qualitative judgements from the rater, proved to have sufficient reliability to serve as a measure of change in upper limb function resulting from treatment. An abbreviation of the U.E.F.T. by means of Guttman scaling, into the Action Research Armtest was accompanied by some redress in the imbalance of items inherent in the U.E.F.T., and by no significant reduction in its reliability. Average savings in testing exceeding 64% were recorded. The Guttman abbreviation of the U.E.F.T. performed creditably in a cross-validation study, including a wider diagnostic grouping of patients. The Armtest may conceivably be of use in evaluating other, e.g. physiotherapeutic treatments of the upper limb.

CHAPTER FIVE

DEVELOPMENT OF MEASURES: 2

INTRODUCTION

The development of the Armtest measure, reported in the previous chapter, grew out of a desire to satisfy the need for a scientific measure of upper extremity function suitable for treatment evaluation. Such a measure perhaps has a stronger affinity with the physiotherapeutic approaches to assessment in hemiplegia reviewed in Chapter Two, in that it is a fairly narrow, specific assessment of function in one limb. However, the generalisation of improvement on such a specific measure, to enhanced competency in everyday activities of life is also an important consideration. Enhancement of such domestic function is usually a primary expectation of the rehabilitee, to whom an isolated improvement on some esoteric measure of upper limb function may be of little comfort.

The undertaking of a study of A.D.L. was motivated by a number of considerations. A survey of currently available measures lead to the conclusion that, although some compromise as between rapidity and comprehensiveness in A.D.L. testing was unavoidable, nevertheless some curtailment of a

lengthy assessment procedure might be achieved by identifying functional as opposed to a priori, logical, groups of items. These groupings, if capable of arrangement into Guttman scales, would permit an hierarchical abbreviated approach to testing, without a corresponding reduction in the range of skills assessed. The grouping of A.D.L. items into functions, by analogy with the scaling exercise which developed Carroll's U.E.F.T. into Armtest, would allow a meaningful comparison to be made between Armtest and A.D.L. function, and hence permit conclusions about the utility of improvement in Armtest score. It might conceivably be possible to include Armtest items in A.D.L. Guttman scales. This would be advantageous, since Armtest items are frequently far more rapidly administered than are A.D.L. items.

Apart from the goal of establishing the concurrent validity of the Armtest and A.D.L., the aim of shortening A.D.L. administration is worthy of pursuit in its own right. Although there may be variation from one centre to another, informal inquiries indicate that frequently, up to half of occupational therapy patient contact time in physical rehabilitation may be absorbed in the testing of A.D.L. A reduction in this would permit the devotion of more time to therapeutic work. A reduction of half in testing time would, on these estimates, be equivalent to increasing occupational

therapy staff establishment by 25% at no further cost to the National Health Service.

An additional benefit accruing from functional scales of A.D.L. might be that concentration on remediation of a deficient movement pattern common to a number of items, might enhance recovery of several activities of daily living, while the present practice of teaching each skill individually is rather more time consuming. An added advantage of such an integrated approach would be to provide both a practical and a theoretical basis for linking more closely physiotherapeutic and occupational therapeutic endeavours on behalf of the same patient. Hitherto, the distinctive professional training of each of these groups has tended not to foster such a joint approach.

METHOD

SUBJECTS

The subjects were 20 hemiplegic stroke patients attending the Astley Ainslie Hospital, Edinburgh. Patients exhibiting gross short-term memory impairment or having overriding disabilities such as blindness were excluded. Degrees of dyspraxia and aphasia were not criteria for exclusion. Sixteen

were female, the mean age was 63.6 years, and the range 37-80.

MATERIALS

The Home Unit in the Astley Ainslie Hospital was equipped to permit testing of the 109 A.D.L. items listed in Table V(1).

TABLE V(1)

Full list of A.D.L. items

ADL 1	STANDING BALANCE
ADL 2	WALK 20 METRES
ADL 3	PROPEL WHEELCHAIR
ADL 4	OPERATE DOOR LEVER
ADL 5	OPERATE LIGHT SWITCH
ADL 6	OPERATE DOOR KNOB AND KEY
ADL 7	WASH, RINSE AND WRING TEATOWEL
ADL 8	PLACE ON PULLEY AND RAISE
ADL 9	FETCH AND ASSEMBLE IRONING BOARD
ADL 10	IRON TOWEL
ADL 11	SWEEP WITH LONG BRUSH
ADL 12	SWEEP WITH SHORT BRUSH AND DUSTPAN
ADL 13	WET MOP PART FLOOR
ADL 14	MOVE BIN ACROSS FLOOR
ADL 15	OPERATE COIN METER
ADL 16	ASCEND AND DESCEND 5 STEPS
ADL 17	GET ON AND OFF BUS
ADL 18	GET INTO AND OUT OF CAR
ADL 19	UPPER GARMENT ON AND OFF OVER HEAD
ADL 20	UPPER GARMENT ON AND OFF FRONT OPENING
ADL 21	LOWER GARMENT ON AND OFF OVER FEET

ADL 22 FIT AND REMOVE APPLIANCE
ADL 23 SHOES ON AND OFF
ADL 24 DRESSING GOWN ON AND OFF
ADL 25 SOCKS ON AND OFF (MEN)
ADL 26 STOCKINGS OR TIGHTS ON AND OFF (WOMEN)
ADL 27 MENSTRUAL HYGIENE
ADL 28 EMPTY AND CHANGE CATHETER BAG
ADL 29 (STANDING) RETRIEVE STICK FROM FLOOR
ADL 30 ON AND OFF CHAIR
ADL 31 GET UP FROM FLOOR
ADL 32 IN AND OUT OF BED (TAKING DOWN COVER)
ADL 33 TIE SHOELACES (USING BOARD)
ADL 34 TAKE GLOVES ON AND OFF
ADL 35 FASTEN TIE (MEN)
ADL 36 FASTEN SCARF (WOMEN)
ADL 37 FASTEN BUTTONS ON BOARD
ADL 38 FASTEN HOOKS ON BOARD
ADL 39 FASTEN BUCKLES ON BOARD
ADL 40 FASTEN ZIP ON BOARD
ADL 41 WIND WATCH
ADL 42 TAKE MONEY FROM PURSE
ADL 43 PRODUCE COINS TO ORDER
ADL 44 OPERATE TELEPHONE
ADL 45 SIGN NAME
ADL 46 SEW BUTTON
ADL 47 USE SCISSORS
ADL 48 ELECTRIC SHAVE (MEN)
ADL 49 APPLY LIPSTICK (WOMEN)
ADL 50 CUT TOE AND FINGER NAILS
ADL 51 BRUSH AND COMB HAIR
ADL 52 STRIP AND MAKE BED
ADL 53 PLUG IN TO LOW POINT, AND SWITCH ON
ADL 54 CARRY COAL BUCKET
ADL 55 PREPARE OPEN FIRE
ADL 56 STRIKE MATCH
ADL 57 DUST WINDOWSILL
ADL 58 OPEN WINDOW
ADL 59 USE CARPET SWEEPER
ADL 60 GET ON AND OFF TOILET
ADL 61 USE TOILET PAPER
ADL 62 FLUSH TOILET
ADL 63 MANAGE CLOTHES AT TOILET
ADL 64 FEEL HOT AND COLD TAPS
ADL 65 SIMULATE WASH AND DRY FACE
ADL 66 SIMULATE WASH AND DRY NECK
ADL 67 SIMULATE WASHING ARMS TO NAILS
ADL 68 SIMULATE WASHING BODY AND BACK
ADL 69 SIMULATE WASHING LEGS AND FEET
ADL 70 SIMULATE WASH AND DRY HAIR
ADL 71 BRUSH TEETH
ADL 72 IN, OUT AND SOAK DENTURES
ADL 73 WET SHAVE
ADL 74 IN AND OUT BATH
ADL 75 DRINK FROM MUG OR STRAW
ADL 76 SUP WITH SPOON
ADL 77 BUTTER BREAD

ADL 78 CUT AND EAT BREAD (KNIFE AND FORK)
ADL 79 EAT WITH FORK
ADL 80 EAT BOILED EGG
ADL 81 TAKE PLATE FROM HIGH CUPBOARD
ADL 82 OPEN SCREW TOP JAR
ADL 83 LIFT BAG OF TINS ACROSS ROOM
ADL 84 OPEN TIN
ADL 85 TURN GAS HOTPLATE ON AND OFF
ADL 86 FILL KETTLE
ADL 87 PUT KETTLE ON HOTPLATE
ADL 88 PLUG KETTLE IN LEVEL SOCKET
ADL 89 POUR HOT WATER INTO TEAPOT
ADL 90 POUR TEA INTO CUP
ADL 91 CARRY LADEN TRAY TO LOW WORKTOP
ADL 92 PUT CUP AND PLATES ON TROLLEY
ADL 93 WHEEL TROLLEY TO SINK
ADL 94 TURN TAPS ON AND OFF
ADL 95 WASH UP CROCKERY
ADL 96 DRY CROCKERY
ADL 97 TAKE PAN AND DISH FROM LOW CUPBOARD
ADL 98 FOLLOW RECIPE
ADL 99 PEEL AND CUT POTATOES
ADL 100 GRATE AND WEIGH CHEESE
ADL 101 BREAK EGGS
ADL 102 BEAT EGGS
ADL 103 DRAIN POTATOES
ADL 104 BEAT ALL TOGETHER
ADL 105 LIGHT OVEN
ADL 106 INSERT DISH IN OVEN
ADL 107 TAKE HOT DISH FROM OVEN
ADL 108 SERVE ONTO PLATE
ADL 109 CLEAN UTENSILS

The selection of items for inclusion was problematic. All published A.D.L. scales referred to in Chapter 2 were scrutinised, as were a range of A.D.L. protocols from local hospitals. Several meetings were held with members of the occupational therapy staff in the Astley Ainslie Hospital and two drafts were rejected before a final selection of items was made. The 109 items were selected to cover, in some depth, as wide a range of activities as possible. Common brands of goods were used to allow replication elsewhere, and details of the equipment used are provided in the Appendices. The range of aids employed for the purpose of score category 3, was determined by contemporary practice in the Astley Ainslie Home Unit. The modest range of aids employed contrasts pointedly with the plethora of ingenious devices manufactured by commercial firms: yet the former proved entirely adequate in use. Presentation of a paper describing a portion of this research provoked several comments from occupational therapists complaining of the unsuitability or lack of necessity for elaborately manufactured aids for A.D.L. Perhaps there is a lesson here to the effect that consumers should be more closely involved in advising commercial firms manufacturing such aids. The range and sources of aids employed, together with the test items for which they were used, are depicted in the Appendices.

The criteria to be employed in scoring were next considered, and it was decided to use a series of score categories which could be applied to all A.D.L. tasks, *vice* the practice in certain other A.D.L. protocols: Carroll (1962); Mahoney & Barthel (1965); Schoening & Iversen (1968); Lawton & Brody (1969); of using scoring criteria specific to the item being assessed. The scoring criteria chosen relate to the degree of dependence upon others in performance of the task. The degree of dependence on others in performing A.D.L. is frequently a consideration in placing the patient following discharge from rehabilitation. It seemed, in this context, entirely appropriate to consider independent completion of a task using an aid or assistive device as an independent and self-sufficient performance. The differentation of the degree of supervision and assistance required in score categories 1 and 2, as depicted in Table V(2) might be expected to relate to decisions regarding whether a patient might be cared for by a relative, or might require to be taken into institutional care.

TABLE V(2)
Scoring Categories

0 - Can perform no part of test.

1 - (If applicable) Performs test partially - can complete only with major assistance.

2 - (If applicable) Completes test with slight help OR supervision recommended for safety.

3 - (If applicable) Completes test with

specified artificial aid.

4 - Completes test safely and independently but takes a longer time or has some difficulty.

5 - Performs test normally.

By the deliberate inclusion of aids it was also hoped to predict the utility or otherwise of that aid for that degree of disability. The prescription of aids which the patient is subsequently incapable of employing appears to be a reasonably frequent occurrence (Lenihan, 1979). The use of relatively objective criteria, in addition to being more meaningful for discerning the patient's needs, was intended to increase replicability.

PROCEDURE

The patients were tested on each applicable item by one of two experienced Occupational Therapists. The Occupational Therapists participating were constrained by the service demands of the department in which they were working as to the time which could be spared for the administration of the 109 item A.D.L. test: but to their great credit were able to test an individual patient over a period of approximately one week. Industrial disputes involving ambulance drivers and unaccustomed near arctic weather conditions took their toll of patient availability, and original hopes of processing up to 40 patients had to be re-appraised so that ultimately data on 20 patients was analysed.

Following completion of the A.D.L. measure, each patient was tested on the Armtest. An inter-item correlation matrix was computed on the A.D.L. data in order to identify test items closely correlated across the patient population. Groups of items forming natural, functional subscales, involving perhaps similar patterns of movement were thus detected, in place of logical, a priori scales (e.g. Dressing, Bathroom, etc.).

The groupings of correlated items were next examined to determine whether they fulfilled the stringent criteria for Guttman scales.* When the term cutting score is used, this means that a patient was deemed to have passed an item when his score equalled or exceeded that score. Since ability or otherwise to function independently is frequently a meaningful basis for classification of the disabled for the purpose of discharge, a minimum cutting score of 3 was appropriate, as this represented the minimum level of competence to perform an individual test item without assistance.

RESULTS

Twenty-three items, listed in Table V(3) were discarded as being insufficiently widely applicable or not suitably correlated for inclusion in a Guttman scale. Eight non-scale items (Table V(4)) were discarded since all patients scored at least

*For a fuller explanation of Guttman scales refer to Chapter 4.

4 on them, and six items (Table V(5)) consisting of male and female variants of similar activities were condensed into three.

TABLE V(3)

Uncorrelated or insufficiently applicable items

ADL	4	OPERATE DOOR LEVER
ADL	5	OPERATE LIGHT SWITCH
ADL	22	FIT AND REMOVE APPLIANCE
ADL	23	SHOES ON AND OFF
ADL	27	MENSTRUAL HYGIENE
ADL	28	EMPTY AND CHANGE CATHETER BAG
ADL	32	IN AND OUT OF BED
ADL	33	TIE SHOELACES
ADL	34	PUT GLOVES ON AND OFF
ADL	36	FASTEN TIE OR SCARF
ADL	38	FASTEN CLOTHING HOOKS
ADL	41	WIND WATCH
ADL	45	SIGN NAME
ADL	46	SEW BUTTON
ADL	63	MANAGE CLOTHES AT TOILET
ADL	68	SIMULATE WASHING BODY AND BACK
ADL	71	BRUSH TEETH
ADL	73	WET SHAVE
ADL	74	IN AND OUT OF BATH
ADL	88	PLUG KETTLE IN LEVEL SOCKET
ADL	93	WHEEL TROLLEY TO SINK
ADL	101	BREAK EGGS
ADL	102	BEAT EGGS

TABLE V(4)

Non-scalable items passed by all patients

ADL	58	OPEN WINDOW
ADL	61	USE TOILET PAPER
ADL	64	FEET HOT AND COLD TAPS
ADL	65	SIMULATE WASH AND DRY FACE
ADL	66	SIMULATE WASH AND DRY NECK
ADL	75	DRINK FROM MUG OR STRAW
ADL	76	SUP WITH SPOON
ADL	94	TURN TAPS ON AND OFF

TABLE V(5)

Equivalent male and female items

ADL 25 SOCKS ON AND OFF (MEN)
ADL 26 STOCKINGS OR TIGHTS ON AND OFF (WOMEN)
ADL 35 FASTEN TIE (MEN)
ADL 36 FASTEN SCARF (WOMEN)
ADL 48 ELECTRIC SHAVE (MEN)
ADL 49 APPLY LIPSTICK (WOMEN)

The remaining 75 items were arranged into 12 Guttman scales, which follow in the body of the text. (Tables V(6) to V(17)). Within each scale, the number in brackets indicates the cutting score applied. The items in each scale are arranged in descending order of difficulty. For each scale, two statistics are quoted, namely the coefficient of reproducibility, which is a measure of the predictability of a respondent's response pattern on the basis of his total score on that scale; and secondly the coefficient of scalability. Nie et al. (1975) recommend that a coefficient of reproducibility of above 0.9, and a coefficient of scalability of well above 0.6, be taken to indicate that a Guttman scale is valid. Names were assigned to the scales following inspection of constituent items.

TABLE V(6)

GUTTMAN SCALE: BALANCE

(CUTTING SCORE IN BRACKETS)

ADL 9 (4) FETCH AND ASSEMBLE IRONING BOARD

ADL	50	(4)	CUT TOE AND FINGER NAILS
ADL	2	(4)	WALK 20 METRES
ADL	17	(4)	GET ON AND OFF BUS
ADL	16	(4)	ASCEND AND DESCEND 5 STEPS
ADL	16	(3)	ASCEND AND DESCEND 5 STEPS
ADL	81	(4)	TAKE PLATE FROM HIGH PRESS
ADL	29	(4)	(STANDING) GET STICK FROM FLOOR
ADL	1	(4)	STANDING BALANCE
ADL	2	(3)	WALK 20 METRES
ADL	1	(3)	STANDING BALANCE

COEFFT. OF REPRODUCIBILITY = 0.9234
COEFFT. OF SCALABILITY = 0.6800

TABLE V(7)

GUTTMAN SCALE: SHOULDERS

ADL	60	(4)	GET ON AND OFF TOILET
ADL	31	(4)	GET UP FROM FLOOR
ADL	13	(4)	WET MOP PART FLOOR
ADL	11	(4)	SWEEP WITH LONG BRUSH
ADL	12	(4)	SWEEP WITH SHORT BRUSH AND DUSTPAN
ADL	105	(4)	LIGHT OVEN
ADL	60	(3)	GET ON AND OFF TOILET

COEFFT. OF REPRODUCIBILITY = 0.9000
COEFFT. OF SCALABILITY = 0.7255

TABLE V(8)

GUTTMAN SCALE: ARMS

ADL	8	(4)	PLACE ON PULLEY AND RAISE
ADL	14	(4)	MOVE BIN ACROSS FLOOR
ADL	24	(4)	DRESSING GOWN ON AND OFF
ADL	19	(4)	UPPER GARMENT ON AND OFF OVER HEAD
ADL	3	(4)	PROPEL WHEELCHAIR
ADL	42	(4)	TAKE MONEY FROM PURSE
ADL	51	(4)	BRUSH AND COMB HAIR
ADL	86	(4)	FILL KETTLE
ADL	69	(4)	SIMULATE WASHING LEGS AND FEET
ADL	82	(4)	OPEN JAR

COEFFT. OF REPRODUCIBILITY = 0.9800
COEFFT. OF SCALABILITY = 0.8667

TABLE V(9)

GUTTMAN SCALE: TWO WRISTS

ADL	99	(4)	PEEL AND CUT POTATOES
ADL	60	(4)	GET ON AND OFF TOILET
ADL	7	(4)	WASH, RINSE AND WRING TEATOWEL
ADL	104	(4)	BEAT ALL TOGETHER
ADL	79	(4)	EAT WITH FORK

COEFFT. OF REPRODUCIBILITY = 0.9400
COEFFT. OF SCALABILITY = 0.7143

TABLE V(10)

GUTTMAN SCALE: TWO HANDS

ADL	84	(4)	OPEN TIN
ADL	91	(4)	CARRY LADEN TRAY TO LOW TOP
ADL	80	(4)	EAT BOILED EGG
ADL	107	(4)	TAKE HOT DISH FROM OVEN
ADL	39	(4)	FASTEN BUCKLE BOARD
ADL	40	(4)	FASTEN ZIP BOARD

COEFFT. OF REPRODUCIBILITY = 0.9333
COEFFT. OF SCALABILITY = 0.7419

TABLE V(11)

GUTTMAN SCALE: ONE HAND

ADL	84	(3)	OPEN TIN
ADL	10	(4)	IRON TOWEL
ADL	20	(4)	UPPER GARMENT (FRONT OPENING) ON AND OFF
ADL	21	(4)	LOWER GARMENT ON AND OFF OVER FEET
ADL	15	(4)	OPERATE COIN METER
ADL	30	(4)	ON AND OFF CHAIR
ADL	37	(4)	FASTEN BUTTONS ON BOARD
ADL	79	(3)	EAT WITH FORK
ADL	104	(3)	BEAT ALL TOGETHER
ADL	108	(3)	SERVE ONTO PLATE

COEFFT. OF REPRODUCIBILITY = 0.9789
COEFFT. OF SCALABILITY = 0.8261

TABLE V(12)

GUTTMAN SCALE: GRIPFORCE

ADL	54	(4)	CARRY COAL BUCKET
ADL	83	(4)	LIFT BAG OF TINS ACROSS ROOM
ADL	6	(4)	OPERATE DOOR KNOB AND KEY
ADL	59	(4)	USE CARPET SWEEPER
ADL	83	(3)	LIFT BAG OF TINS ACROSS ROOM
ADL	87	(4)	PUT KETTLE ON HOTPLATE
ADL	106	(4)	INSERT DISH IN OVEN
ADL	62	(4)	FLUSH TOILET
ADL	85	(4)	TURN GAS HOTPLATE ON AND OFF
ADL	89	(4)	POUR HOT WATER IN TEAPOT
ADL	57	(4)	DUST WINDOWSILL
ADL	90	(4)	POUR TEA INTO CUP

COEFFT. OF REPRODUCIBILITY = 0.9333
COEFFT. OF SCALABILITY = 0.6923

TABLE V(13)

GUTTMAN SCALE: PINCH

ADL	78	(4)	CUT AND EAT BREAD (KNIFE AND FORK)
ADL	78	(3)	CUT AND EAT BREAD (KNIFE AND FORK)
ADL	77	(4)	BUTTER BREAD
ADL	100	(4)	GRATE AND WEIGH CHEESE
ADL	67	(4)	SIMULATE WASHING ARMS TO NAILS
ADL	67	(3)	SIMULATE WASHING ARMS TO NAILS
ADL	100	(3)	GRATE AND WEIGH CHEESE
ADL	77	(3)	BUTTER BREAD

COEFFT. OF REPRODUCIBILITY = 0.9750
COEFFT. OF SCALABILITY = 0.8857

TABLE V(14)

GUTTMAN SCALE: ADROIT

ADL	26	(4)	STOCKINGS TIGHTS OR SOCKS ON AND OFF
ADL	96	(4)	DRY CROCKERY
ADL	44	(4)	OPERATE TELEPHONE
ADL	49	(4)	ELECSHAVE OR LIPSTICK

COEFFT. OF REPRODUCIBILITY = 1.000
COEFFT. OF SCALABILITY = 1.000

TABLE V(15)

GUTTMAN SCALE: COMPLEX 'A'

ADL	52	(4)	STRIP AND MAKE BED
ADL	97	(4)	TAKE PAN AND DISH FROM LOW PRESS
ADL	109	(4)	CLEAN UTENSILS
ADL	95	(4)	WASH UP CROCKERY

COEFFT. OF REPRODUCIBILITY = 0.9750
COEFFT. OF SCALABILITY = 0.7143

TABLE V(16)

GUTTMAN SCALE: COMPLEX 'B'

ADL	70	(4)	SIMULATE WASH AND DRY HAIR
ADL	72	(4)	IN, OUT AND SOAK DENTURES
ADL	53	(4)	PLUG IN TO LOW POINT AND SWITCH ON
ADL	103	(4)	DRAIN POTATOES
ADL	92	(4)	PUT CUP AND PLATES ON TROLLEY

COEFFT. OF REPRODUCIBILITY = 0.9692
COEFFT. OF SCALABILITY = 0.7778

TABLE V(17)

GUTTMAN SCALE: PLAN

ADL	18	(4)	GET IN AND OUT OF CAR
ADL	56	(3)	STRIKE MATCH
ADL	98	(4)	FOLLOW RECIPE
ADL	47	(4)	USE SCISSORS
ADL	55	(4)	PREPARE OPEN FIRE
ADL	43	(4)	PRODUCE COINS TO ORDER

COEFFT. OF REPRODUCIBILITY = 0.9667
COEFFT. OF SCALABILITY = 0.8333

FURTHER ANALYSIS

Intercorrelation of A.D.L. scales

The scores obtained by the individual subjects participating in the study on each of the Guttman scales of A.D.L. items which were obtained in this way, were next computed. This was done prior to obtaining the product-moment correlations between the different Guttman scales. This analysis was made in order to check further for redundancy. The resulting correlation matrix appears in Table V(18).

Intercorrelation A.D.L.: Armtest

Since one of the purposes in investigating A.D.L. had been to determine the validity of the Armtest in relation to everyday functioning, the correlation of each of the A.D.L. scales with each of the Armtest sub-scales was next computed. The Armtest data are presented for the impaired side only, since most subjects, being hemiplegic, obtained a near maximum score with the unaffected upper limb. The A.D.L.: Armtest correlation matrix appears in Table V(19).

Calculation of savings deriving from hierarchical administration of A.D.L. items

It was now necessary to determine what practical benefit might accrue from taking advantage of the inherent hierarchical structure of the Guttman scales

TABLE V(18)

Intercorrelation of A.D.L. Guttman Scales

	Balance	Shoulders	Arms	Two wrists	Two hands	One hand	Gripforce	Pinch	Plan	Adroit	Complex A	Complex B
Balance		0.5944*		0.7263**		0.4503@			0.4534@			
Shoulders			0.6286*	0.7064**		0.5725*	0.7525**		0.5394@		0.5727*	
Arms				0.4632@	0.4809@	0.6732**	0.5665*				0.4985@	
Two Wrists						0.5612*			0.5424@		0.4686@	
Two Hands												
One Hand							0.4695@				0.5903**	
Gripforce											0.4845@	
Pinch												
Plan												
Adroit												
Complex A												
Complex B												

KEY

@: $p < 0.005$

*: $p < 0.01$

**: $p < 0.001$

NOTES

(1) Non-significant correlations omitted.

(2) All tests two-tailed.

TABLE V(19)

Intercorrelation of Guttman A.D.L. and Armtest Measures
(Significant Correlations Only)

A.D.L. SCORES / ARMTEST SCORES	GRASP	GRIP	PINCH	GROSSMT.	TOTAL
BALANCE					
SHOULDERS					
ARMS		0.4460@		0.4542@	
TWO WRISTS	0.4676@	0.4884@			0.4629@
TWO HANDS	0.5593*	0.5528@	0.6065*	0.4828@	0.5753*
ONE HAND					
GRIPFORCE					
PINCH	0.8682**	0.9104**	0.8493**	0.8562**	0.8932**
PLAN					
ADROIT					
COMPLEX A					
COMPLEX B					

of A.D.L. which had so far been identified. To recapitulate: seventyfive items from the original 109 item test were found to be suitable for inclusion in Guttman scales. Eleven of these featured in the Guttman scales, at two different score levels (3,4). A further one item featured thrice, at two different score levels (3,4,4.). The total number of non-duplicated test items was therefore eightyseven, since it seems logical to consider testing a patient using an aid as a discrete activity from testing him without an aid, because the procedure and actions involved on the two occasions must necessarily differ. Hence in calculating savings in test items accruing from hierarchical administration, total savings were expressed as a ratio of a test of the potential length of eightyseven items. Savings within individual scales were expressed as a ratio of the number of test items within that scale. A deck of SPSS COMPUTE and IF cards was compiled to simulate running each of the subjects who had participated in the A.D.L. study through the eightyseven item test, according to the following plan. Within each scale, the empirically most difficult item was first administered. If the subject attained or exceeded the cutting score indicated in brackets following the item number (see Appendix), then testing on that subscale could safely be discontinued. This was

because it is a property of Guttman scales that success on more difficult items predicts success on items of lesser difficulty. If the cutting score on the most difficult item were not attained, the least difficult item was next administered. Failure to attain the cutting score for the least difficult item within that scale, predicts inability to pass any more difficult item at the required score level; and so testing on that scale could be terminated, in that eventuality. Attainment of the required cutting score for the least difficult item necessitates administration of the remaining items within the scale, in ascending order of difficulty, until the subject fails to attain the required cutting score on any item, when testing on that scale may safely be terminated. A specimen protocol of such an abbreviated, Guttman scaled A.D.L. is presented, together with instructions and examples, in an Appendix. In Table V(20) there are displayed the savings, in terms of test items not required to be administered, resulting from the simulated hierarchical method of administration just described.

DISCUSSION

Before proceeding to discuss the various findings resulting from the A.D.L. study, certain reservations must be expressed regarding the findings. A weakness of the present study resides

TABLE V(20)

Tabulation of Savings (Items Untested) Accruing from Guttman A.D.L.

SCALE	MEAN SAVINGS	MINIMUM	MAXIMUM	PER CENT
BALANCE	6.35	2	10	57.72
SHOULDERS	4.10	0	7	58.57
ARMS	4.30	0	9	43.00
TWO WRISTS	1.55	0	4	31.00
TWO HANDS	2.20	0	5	36.66
ONE HAND	5.65	0	10	56.50
GRIPFORCE	6.75	0	11	56.25
PINCH	3.70	0	7	46.25
PLAN	2.80	0	5	46.66
ADROIT	2.85	0	3	71.25
COMPLEX A	2.25	0	3	56.25
COMPLEX B	3.45	0	4	69.00
TOTAL	45.95	21	77	52.82

in the relatively small number of patients participating. As was stated earlier, it had been intended to process forty hemiplegic patients through the full 109 item A.D.L. protocol. This was, however, frustrated by the relatively small amount of time which the Occupational Therapy staff were able to devote to the project, and was exacerbated both by an industrial dispute involving ambulance drivers, and by unaccustomed bad weather conditions. The patients participating were largely day-patients. It would also be of interest to conduct a reliability study, in order to compare the level of agreement between independent therapists' ratings of the same patient. In so far as the author is aware, the classic psychometric concept of inter-rater reliability has not been systematically studied in the area of A.D.L. testing.

In replying to the first reservation delineated above, the author cannot but agree with the desirability of a further replication of this Guttman scaling of the original 109 item A.D.L., on another group of patients with the same diagnosis. However, the requirements which must be satisfied before a scale of items can be considered a Guttman scale, are very stringent indeed. This, coupled with the fact that the groupings of items obtained seem to make logical sense, give grounds for reasonable confidence in predicting that the Guttman scales here described will survive further replication. A

really thorough going study which encompassed both a replication of the findings obtained, in addition to a reliability study, would require rather more in terms of resources than was available for the present study. At the time of writing enquiries are proceeding regarding the feasibility of obtaining support on such a scale. Without encroaching into matters perhaps best considered later in the thesis, one might suggest that such a study might include a cross-validation of the Guttman A.D.L. on groups of patients under other diagnoses, as for instance rheumatoid arthritis, multiple schlerosis, and other appropriate diagnostic groups.

Content and composition of derived scales

It was gratifying to note that, in the event, the original A.D.L. protocol condensed into meaningful, statistical, groupings of items. One could not be sure in advance that this would be the outcome, particularly since, from a commonsense point of view, some of the operations involved are fairly complex, involving cognitive, perceptual and motor abilities. One interesting outcome has been that items with a higher cognitive content, certainly the Guttman scale Plan, and arguably the Guttman scales Complex 'A' and Complex 'B', have precipitated out into identifiable subscales. Another interesting feature, is that upper extremity function is seen to dominate competency in

Activities of Daily Living. This is particularly important, since it is known that full functional recovery of the upper limb is considerable rarer amongst stroke patients than is functional recovery of the lower limb. (Wahle, 1973). Passing to consider certain of the scales in turn, it may be said of the first, namely Balance, that this is a composite scale which includes two differentiable components, each having its own internal Guttman structure. One consisted of items wherein the subject's centre of gravity changed relatively slowly and predictably, the other in which the centre of gravity shifted awkwardly and in an unpredictable way. However, it was found that items from both scales could be grouped together into a single Guttman scale which comprehended both. Component items of the Guttman scale in which the centre of gravity shifted unpredictably, were A.D.L. numbers 9, 50, 17, and 16. One interesting feature which is demonstrated in the Balance scale, is that performance on this scale can be used to predict the extent to which a patient is capable of making use of various aids or assistive devices (score level of three). This is particularly important, since clinical staff involved in the issue of these aids occasionally find that patients are incapable of benefiting from aids which are supplied to them. This negative aspect is seen to be of equal importance as the positive value of the scale in predicting functions which could be performed

were the appropriate aid supplied. Whilst considering this, it is interesting to note that a substantial number of test items were satisfactorily passed by every patient. (Table V(4)). This may be a characteristic particular to hemiplegic patients, who generally retain substantial functional use of the side contralateral to the paralysis. The contents of Table V(11) can be seen to require only one good functional hand, whereas the contents of Table V(10) require two relatively functional hands for successful completion. The same can also be said of Table V(9). The reader may note in the Tables detailing the contents of the various scales, that on occasion a test item may be spotted which does not appear strictly to coincide with the label attached to the scale. It is recognized that this has occasionally happened, but the policy in selecting names for the scales was to choose the descriptive term which best fitted the overall grouping of scale items. Nevertheless, the Guttman scales described in the text are statistically valid groupings of items. Since many of the Guttman scales and their contents are self-evident, it is perhaps worthwhile to focus attention on Tables V(14) - V(17) which may cause some puzzlement to the reader. The Guttman scale Adroit, Table V(14), consists of four items, in the execution of which a certain amount of delicacy or dexterity is required. Although the meaning of the scales Complex 'A'

and Complex 'B' (Tables V(15) and (16)) is not entirely clear, both of these seem to consist of items which involve the execution of a sequence of activities, sometimes over a period of time. It is difficult to conceive of any unitary motor pattern which is common to these activities, and it may be that several abilities are relevant in successful completion of these items. The author tentatively suggests that scales Complex 'A' and Complex 'B' may to some extent provide a measure of apraxia. The praxic element is, however, clearer in the scale Plan. This consists of a series of items which involve the performance of a sequence of actions in a definite order. For the benefit of readers puzzled by the inclusion of A.D.L. 56, the task of striking a match, one should point out that this is restricted to individuals who require the use of an aid in order to strike a match. This aid consists of a stand in which the match box must first be placed. The author is reasonably confident in claiming that the scale Plan has identified a cognitive element in activities of daily living. This is of particular interest, since cognitive testing of the disabled patient has tended to occur in isolation from any consideration of the relevancy of such an assessment as predictive of ability to function in an everyday environment. A fuller discussion of this was provided earlier in Chapter 2.

One was perhaps rather surprised to find that the cognitive dimension did not intrude to a greater extent into the activities of daily living assessment. Its effect may have been limited by the extent to which the therapists both explained and demonstrated, if necessary, the actions which the patient was required to perform. It must also be remembered that the patients did not suffer from grossly evident impairments of cognitive function. Perhaps, had the net been cast wider, a more grossly evident cognitive dimension may have been identified. However, it must also be pointed out that the patients participating were considered to be relatively characteristic of the population referred for A.D.L. assessment following stroke.

Mention should be made of the items which were passed by all the patients and of the items which were insufficiently correlated or applicable for inclusion in a Guttman scale. Table V(4) contains the items which were passed by all the patients. It can readily be seen that the items contained in Table V(4) consisted of fairly simple movements, which were in every case manifestly easier than those listed in Guttman Scale One Hand (Table V(11)). Hence, even a hemiplegic patient, who retained a reasonably functional upper limb on the unimpaired side, could satisfactorily perform all items in Table V(4). It would be of interest to determine whether a second

group of hemiplegic patients, chosen for cross validation purposes, would also pass all items contained in that Table. Table V(3) contains a mixture of items. The items range from the essential (A.D.L. 63) to the esoteric (A.D.L. 27) to the relatively trivial (A.D.L. 41). The fact that none of these items has been included in the Guttman scales does not imply that performance on these items should not be tested, if relevant for a particular patient. With the younger female hemiplegic patient, for instance, A.D.L. 27 menstrual hygiene would obviously be relevant. The women patients participating in the study happened to be sufficiently elderly to have ceased to menstruate. It is suggested that if a comprehensive A.D.L. assessment is required, items included in Table V(3) should be administered, if appropriate; however, there is no Guttman structure inherent in this scale. Thus success or failure with one item in no way predicts performance on another.

Two general points may be made about the grouping of A.D.L. items into the functional scales which have been identified. The first observation is that identification of particular defective patterns of movement may allow improvement on a wider number of A.D.L. items to be brought about, by directing therapy at the defective pattern. That is, instead of, or perhaps in addition to, teaching

individual methods of overcoming difficulties in performing Activities of Daily Living, therapy may be directed towards remedying a particular function. In this context, it should be noted that many of the A.D.L. scales correlated well with the Grip subscale of Armtest (Table V(19)). Might it be that intensive therapy aimed at improving the Grip function, could lead to improvement in a wide range of A.D.L. activities? Similarly, under Balance, are subsumed a diverse range of daily living functions. Might not an intensive course of therapy directed towards improving the balance sense, or towards compensating for its loss by developing reliance upon other kinds of cues, not lead to improvements over this relatively wide range of activities? Indeed, in examining many A.D.L. scales, it is difficult to discern any particularly powerful reason why activities should be grouped as they have been hitherto, under categories such as kitchen, washing, dressing and so on. It would have been more understandable, had they been traditionally grouped in terms of the patterns of movement identified in the present study, or even alternatively, by grouping in terms of the degree of assistance from others which the activities might demand.

The second point alluded to above, concerns the possibility that the groupings of A.D.L. items

identified in this study, may have implications for the design and prescription of assistive devices. Might it be for instance, that some kind of external feedback device could assist individuals who have to some degree lost their sense of balance? In this context one might consider for example circuitry incorporating mercury switches, which are sensitive to gravity, and could be set to trigger a buzzer or other warning signal when a preset degree of inclination from the vertical were exceeded. Where a degree of apraxia were present, could some form of external memory aid be devised? This might range from, at the simplest level, a series of cards containing sequences of instructions where a sequence of activities were desired, through to the invention of some device, not yet devised, which relied upon micro-processor technology and recent developments in the generation of speech by solid state micro-processor circuitry. Before proceeding to discuss the inter-correlation of A.D.L. scales, mention may perhaps be made of a third advantage which may result from the identification of functional groups of A.D.L. items. This is the possibility that knowledge of performance on a handful of items may enable predictions to be made over a large range of activities. The extent to which this now appears possible, and the advantages in terms of savings in test administration will be considered for discussion shortly.

Inter-correlation of A.D.L. Scales

Table V(18) shows the inter-correlation of the various component scales of the A.D.L.. From this it can be seen that, although there is a moderate degree of association between the various scales, in no case does this approach a level of correlation which indicates any redundancy or duplication. More than one half of the correlations obtained did not attain a statistically recognised level of significance.

Inter-correlation A.D.L.: Armtest

Table V(19) summarises the significant correlations found as between scores on the Guttman A.D.L. scales, and scores on the Armtest sub-scales, described in the previous chapter. It should again be stated that the correlations were computed for the impaired side only, since many of the patients participating, achieved near maximum scores with their unimpaired arm, when tested on the Armtest. As expected, certain A.D.L. scales do not correlate, since Armtest is a measure of upper extremity function. Hence, A.D.L. scales Balance, and Plan do not yield significant correlations with any of the Armtest sub-scales. The activities included in the A.D.L. scales Gripforce, Adroit, Complex 'A' and Complex 'B' were perhaps not sufficiently reliant upon skill at the kinds of motor patterns assessed in the Armtest scales. The

lack of correlation between the GROSSMT scale of the Armtest, and the Shoulders A.D.L. scale, may perhaps be due to a lack of correspondence between the patterns of movement required to perform these activities: however, some degree of movement at the shoulder was required to perform each of these GROSSMT Armtest items. The fact that the A.D.L. scale One hand does not correlate with any of the Armtest sub-scales may well be understood in the following way: satisfactory performance on the A.D.L. scale One hand, requires only one functional hand to complete the activity satisfactorily; for the hemiplegic patient, the arm used would normally be that belonging to the unimpaired side, and since the Armtest data reported here were obtained from the impaired limb, this explains the lack of any significant correlation. By the converse of this argument, the A.D.L. scales Two hands and Two wrists require adequate function in both limbs, and hence if the impaired limb is sufficiently functional then adequate scores should be obtained on these two A.D.L. scales. Hence, the correlation between these and the Armtest scales.

A general observation may perhaps now be offered. It was stated earlier in this chapter, that the scales of A.D.L. activities which resulted from the present analysis indicated that A.D.L. relies heavily upon upper extremity function. This supports the decision

to investigate the effects of treatment in facilitating recovery of upper limb function, reported in the following chapter. Furthermore, the fact that sub-scales of Armtest have been shown to correlate with A.D.L. scales, further justifies its use as a dependent variable with which to measure recovery. This is because, in addition to being relatively quick and reliable in administration, Armtest correlates with an external criterion measure, namely ability to perform activities of A.D.L.. Hence, it is likely that gains in Armtest scores reflect a recovery of function which is likely to be of use to the patient. Thus, Armtest is likely to prove a more stringent test of the efficacy of a treatment, than would be the demonstration of a statistically significant increase in micro-voltage recorded from a muscle group. The possibility of merging A.D.L. and Armtest items within comprehensive Guttman scales was considered. This might have been of value, on the grounds of rapidity in test administration, since the Armtest items are generally quicker to administer than are the A.D.L. test items. However, one is unfortunately constrained by the procedures at one's disposal, and it is unfortunate that the S.P.S.S. Guttman Scale sub-program restricts the number of items included to twelve. This is because any substantially larger number of items would very quickly exceed the

core limitations of the computer. It is conceivable that a solution might be found to this problem, by inserting only one Armtest item, at one cut-off point, at a time, in order to determine its relative difficulty level in relation to the pre-existing A.D.L. scale items.

Calculation of savings deriving from hierarchical administration of A.D.L. items

It was claimed earlier that an advantage of a Guttman scale approach to A.D.L. testing would be the savings in testing time that this might confer. If items can be arranged into a series of unidimensional scales, then it follows that an individual's performance on each of the items of that scale can be ascertained without necessarily requiring to test each item individually. Table V(20) indicates the extent of the savings which have accrued from such administration in the population under study. If the savings in terms of items not tested can be equated with savings in testing time, then a reduction of slightly over 50% has been achieved. One would of course be more sure about the generalisability of this finding to other groups of patients with the same diagnosis, following further cross-validation studies. However, these results are extremely encouraging, and perhaps point the way to a more rational method of assessing A.D.L.. It can also be seen from the same Table, that the savings are

spread fairly evenly across all the sub-scales of the A.D.L. test. The prospect of such savings provides an alternative to the dilemma whereby therapists hitherto have had to decide between a general, superficial assessment, performed on a large number of patients, or an extensive assessment performed on only a few. By using the Guttman A.D.L., a therapist may ascertain a patient's likely performance over a wide range of activities, without having to test the patient on every one of these. If a therapist requires to take less time in testing each patient, this time can be allocated in several alternative ways. The most obvious would be either to process a larger number of patients, or to devote more time to therapy with the patient, although one would obviously require that a further cross-validation be performed, again using a group of hemiplegic patients, prior to release of this version of A.D.L. for more general use.

Since the possibility of re-structuring A.D.L. assessment in this way has now been demonstrated, another possible development from this study can be discerned. This would be to attempt to apply the same Guttman scaling procedure, to A.D.L. scales given to groups of patients with other diagnoses. For instance, it is rather likely that a similar Guttman structure applies with groups of amputees. Although the pattern of scales which emerged might

differ from that obtained in the present study, it would also be of interest to determine the Guttman structure of A.D.L. when applied to a group of patients with multiple schlerosis. In this way, one might see eventually a series of studies, which resulted in the derivation of Guttman scales of A.D.L. separately for patients with diagnoses as diverse as rheumatoid arthritis and mental handicap. In each case one might expect the findings to provide a rational basis for rehabilitation. When satisfactory validation reliability and cross-validation studies had been effected, and sufficient norms accumulated, such a development might merit widespread adoption for routine clinical use.

CONCLUSIONS

The work reported above represents the application of traditional, psychometric statistical methods to the field of A.D.L. assessment. Unfortunately, the resources were not available to allow a thorough going assessment of the validity and the inter-rater reliability of the said test; however, the correlations obtained with the Armtest described in the previous chapter, do provide some evidence of the external validity of the A.D.L. scales here described. A methodology for restructuring A.D.L. measures has been described which produces statistically derived clusters of items, which appear to have in common certain patterns

of movement or functions. The scales obtained were found to rely heavily upon upper extremity function, and the importance of the preservation or recovery of this for performance of many activities of daily living was thereby demonstrated. This further emphasised the desirability of evaluating treatments likely to be effective in improving the recovery of upper extremity function amongst hemiplegics. The scales obtained were found to be moderately correlated, and the pattern of inter-correlation obtained as between the A.D.L. and the Armtest was interpreted as conferring some degree of mutual validity. Lastly, it was shown that a considerable abbreviation in testing could be achieved by adoption of an hierarchical method of administration, which utilised the properties inherent in the derived Guttman structure.

CHAPTER SIX

ELECTROMYOGRAM BIOFEEDBACK THERAPY:

TREATMENT EVALUATION

Introduction

In an earlier chapter it was noted that the upper limb recovers more slowly and to a lesser extent, in hemiplegia, than does the lower. (Wahle, 1973). Furthermore, from the correlational study of A.D.L. content reported in the previous chapter, it was seen that upper limb function underlay a majority of the derived scales of A.D.L. These two considerations emphasised the importance of developing and testing treatments for that limb, a concern shared by others (Langton Hewer, de Souza, & Miller, 1979). From a review of the literature, it was seen that claims had been made regarding the efficacy of biofeedback of electromyogram in facilitating recovery of functional use of the hemiplegic arm and hand. Reports varied regarding the degree of success achieved, and in many instances were uncontrolled in respect of patient selection, experimenter effect, and placebo effect, and utilised crude outcome measures, frequently without established reliability or validity. In view of the striking results reported by Andrews (1964), it was decided to undertake a series of studies to evaluate the efficacy of E.M.G. biofeedback in restoring

upper extremity function in hemiplegia.

Plan of investigation

The process of developing measures of upper limb function for use as dependent variables has been described in the fourth chapter of this work. Evidence establishing the validity of the Armtest, by virtue of correlation with a measure of A.D.L., was provided in Chapter Five. It was argued that it would have been impractical to have used repeated measures of A.D.L. as a dependent variable in evaluating treatment, because of the duration of the A.D.L. test. Reliance upon recorded E.M.G. activity alone as a dependent variable was rejected as insufficiently indicative of the likely utility of any treatment effect.

The dependent variables having been selected, a sequence of experimental studies to test certain hypotheses was next devised. These underwent revision and further development in the light of successive findings. The rationale underlying the several experiments, followed by an exposition of the considerations which weighed in the choice of experimental design, and of subjects, will next be presented.

In order to allow the experimenter some experience of the equipment, and of the niceties of the treatment technique, two single case pilot studies were first conducted. This also permitted

a trial of the outcome measures. The pilot studies were limited to two single cases, in view of the investment of time which was required in the treatment of each patient. There then followed two experiments, one comparing E.M.G. biofeedback treatment with a feedback-placebo condition, and the second comparing the feedback-placebo condition with a control group for the passage of time. For the purposes of these experiments, Andrew's (1964) conclusions were accepted at face value, and patients suffering dense hemiplegia affecting the upper limb were selected for inclusion. The negative findings resulting from this study led to further experimentation to clarify whether either of two explanations could account for the discrepancy between Andrew's results and those which had just been obtained. Although Andrews had subsequently reported success (1978) using both surface and needle electrodes, conceivably the higher degree of specificity, and the greater sensitivity afforded by the latter, might have accounted for his 1964 results, which were achieved using needle electrodes only. A third experiment was therefore conducted, comparing exposure to E.M.G. feedback with needle electrodes, E.M.G. feedback with surface electrodes and placebo feedback administered randomly in six permutations to patients with dense hemiplegia. Treatment duration conformed to that described by Andrews (1964). The results again yielded no

differences between treatments. Consequently, a fourth experiment was conducted, where patients participating suffered only hemiparesis affecting the upper limb. This was motivated by the consideration that the severity of the impairment, reflecting crudely, but not necessarily, either the brain volume damaged or excised or the level of the brain structures affected might predetermine the capacity for recovery. For instance, Finger, Walbran & Stein (1973) showed that animals operated on to inflict a single massive brain lesion, recovered less well than animals suffering equivalent or greater tissue damage inflicted in a series of small lesions. These findings can be understood in terms firstly of the greater mechanical difficulty involved for neuronal growth in traversing an extensive lesion; and secondly, of the degree of confusion caused when many pre-existing engrams or the "software", to use a computer term, has been lost.

Choice of experimental design

In recent years, the concept of single-case experimental designs has been developed as a means of overcoming the sometimes prohibitive cost, in time and money, not to mention the difficulty of matching large groups of subjects, resulting from the conventional group designs traditionally associated with medical and psychological experimentation

(Campbell & Stanley, 1966; Hersen & Barlow, 1976; Kratochwill, 1978). There is, in addition, an inherent wastefulness in expending perhaps two-thirds of the experimental effort, in treating placebo and control groups. The costliness of such designs increases if ethical considerations require a crossover of patients receiving inert or nil treatment, to the experimental treatment, should it prove to be active. The advantages of single case designs, do, however, extend beyond economy. Since each individual undergoes multiple treatments, he may serve as his own control, and thus obviate problems regarding comparability. The intensive investigation of the individual allows a finer degree of observation to be maintained in discerning the progress of the subject over time. The operant technique of reversal, if applicable to the phenomenon under investigation, confers the additional advantage of establishing more unequivocal evidence of the degree of control exerted by the independent variable on the dependent variable, in that the experimental variable is applied, then withdrawn or sometimes reversed. While Skinner (1938) traditionally eschewed statistical analysis of single case data, progress has been made in devising appropriate statistical treatments (Kazdin, 1976). Single case methodology is thus ideally suited to the investigation of experimental treat-

ments of previously undetermined, or uncertain, effectiveness, since a large amount of experimental time does not require to be committed in a hazardous gamble, and since detailed information can be collected by continuous assessment.

However, the advantages of single case designs are bought at some cost, and that is principally a reduction in the generalisability of the results. Single case findings require confirmation in systematic replications, in order to establish their more general applicability. A partially satisfactory answer to this problem has been achieved by the adoption of multiple single case designs, where predictions are made regarding the outcome of a series of single case studies, which together form a larger experimental strategy (Campbell & Stanley, 1966). An example might be an experiment wherein each subject received three experimental treatments in one of the six possible permutations. Conclusions might be drawn from the timing of changes occurring in the dependent variable, differentially across subjects. A sophisticated paradigm for a multiple single case design has been described by Revusky (1967). Revusky compares an experiment to a game of chance, such as roulette, or the casting of a die, where each possible outcome is equiprobable. The experimental effect is tested by its ability to influence this random quality. Let us suppose that we wished to test an experimental treatment against

a placebo treatment. A minimum of four subjects would be required to allow the possibility of generating a statistically significant result ($\frac{1}{4}! = {}_2\frac{1}{4}$). The four subjects participate in a multiple single case design wherein the experimental variable is introduced in stepwise fashion over three blocks of time, viz:

Subject 1	Placebo	Placebo	Placebo
Subject 2	Placebo	Placebo	Experimental
Subject 3	Placebo	Experimental	Experimental
Subject 4	Experimental	Experimental	Experimental

The subjects must be assigned <u>at random</u> to one of the sequences of treatment. If the two treatments are equally effective, or equally ineffective, then chance determines which subject first shows an increase in the dependent variable. However, in order for a statistically significant treatment effect to be evident, subject 4 must improve before subject 3, who must improve before subject 2, who in turn must improve before subject 1. The probability of such an outcome occuring by chance is ${}_2\frac{1}{4}$. Although the design appears simple, it does in fact constitute a stringent test of the efficacy of the treatment, which must affect all individuals similarly if it is to be proven significant. Additionally, the time frame set by the design must coincide with the time scale within which the treatment effect may be produced. A more significant

treatment effect is possible with the expansion of the design further, viz:

Sj. 1	P	P	P	P	P
Sj. 2	P	P	P	P	E
Sj. 3	P	P	P	E	E
Sj. 4	P	P	E	E	E
Sj. 5	P	E	E	E	E
Sj. 6	E	E	E	E	E

The probability of improvement occuring in subject 6 before subject 5 and so on is here $\frac{1}{6}! = \frac{1}{720}$. Although predictions so far have been in terms of the likely sequence of improvement, (paradoxically, Revusky's examples related to the effects of poison) there remains the possibility of making predictions about the likely magnitude of improvement, in that subjects receiving the experimental treatment longest might be expected, on certain assumptions, to benefit most.

A particular advantage of Revusky's design is that, unlike reversal, it is suitable for irreversible treatment effects. It is of particular interest here since a patient who has achieved some genuine degree of recovery in a hemiplegic limb as a result of biofeedback therapy, is unlikely to revert to the pristine state when that treatment is withdrawn. Thus Revusky's design, although devised initially with a view to applications within pharmacology, seems an appropriate design with which to investigate biofeedback. Its inherent economy is of

particular value in a treatment where contact with the patient requires to be intensive. It therefore forms the basis of experiments, 1, 2, & 4 which are described later below.

PILOT STUDY

METHOD

SUBJECTS

Two subjects participated, each suffering a residual hemiparesis. One subject (G), was female, single, and aged 46 years and had suffered an encephalitic illness at the age of 16 years which resulted in disturbances of speech and motor function. The motor disturbance was bilateral at first, but eventually a partial recovery took place, and speech functions returned apparently to normal. At the time of entering the study, Miss G. worked as a clerkess in a local government office. She had a residual paresis of the left arm, which was habitually flexed, and the fingers and thumb of her left hand could only with difficulty be straightened by the experimenter. By her own account, and that of her G.P., her condition had been static for many years.

The second subject, Mr. F., was a trawlerman, aged 50 years, who had suffered an industrial accident three years previously, when a block of ice had fallen on his head. His wife had left him, taking their two children with her, to live with another man, and during the course of treatment, he admitted to feelings of depression. His right

arm was principally affected, but on testing he scored the maximum score on Armtest. His principal difficulty was a residual clonus, which made eating and drinking particularly difficult. Mr. F. therefore presented a different aspect of disability from that of Miss G., and was included for that reason.

MATERIALS

Recordings of electromyogram activity, and feedback therapy, were conducted using an E.M.G. 90 biofeedback amplifier manufactured by Biofeedback Systems Ltd. The device was battery operated, hence portable, and had common mode signal rejection and a 50Hz filter to suppress external interference. Recordings were made using disposable Dracard surface electrodes, filled with Neptic electrode gel. The E.M.G. 90 required an input from three electrodes, the two outer electrodes normally being equidistant from the central or earth electrode. The device was modified to produce integration of E.M.G. using a time constant of 0.2, 0.5 or 2 seconds. Signal output was 1mV per 1μV peak-to peak of raw E.M.G. activity, indicated on a panel meter. The feedback signal could be delivered through a loudspeaker integral with the cabinet, or via a pair of 8 Ohm headphones. Three modes of auditory output were available, however a series of clicks of variable frequency according to recorded

E.M.G. activity, was selected as standard. The sensitivity of the amplifier, and hence of the feedback signal, was switchable to accommodate E.M.G. activity within the ranges 0-10, 0-100, or 0-1000μV, but independently of the electrical output to the chart recorder described below. Within a given preselected range of sensitivity, the responsiveness of the auditory signal could be varied to allow "shaping" of a response. A line output from the E.M.G. 90 was connected to a d.c. amplifier switchable to 1x or 10x amplification, and thence to a Devices MX6 chart recorder, at the 1V input connection. An input signal to the recorder of 2μV thus produced a 1mm pen deflection at the higher amplification. The chart speed was 25 divisions per 10 seconds. The Armtest, described in an earlier chapter, was administered as a measure of upper extremity function prior to commencing the E.M.G. recordings and feedback.

PROCEDURE AND RESULTS

The Armtest was first administered to each subject. The muscles of the affected arm and hand were next palpated in order to determine a suitable site for electrode placement. The electrode site was cleansed with acetone prior to application of the electrodes. In the case of Miss G. the muscles chosen were the biceps and triceps, and the thumb abductors of the left hand. For Mr. F., the

electrode site chosen was above flexor carpi radialis and flexor carpi ulnaris, a site particularly active during tremor. Voas (1952) had earlier reported considerable consistency in measured E.M.G. levels from a variety of sites, including the muscles of the forearm. In particular, surface electrodes, in contrast to needles, summate activity over a wider area underlying the skin and it was not found necessary to mark the skin from session to session in order to obtain consistent readings. This held for every patient studied in the entire series of experiments reported in this chapter.

The strategy employed differed between the two patients. The conduct of Mr. F's treatment will be described first. Recordings were taken of E.M.G. activity evident at rest in the right arm, without feedback. The modal E.M.G. was in the range 5-10μV. The strategy adopted initially was for Mr. F. to move his affected arm in a horizontal plane, at chest level, whilst attempting, under feedback conditions, to minimise the E.M.G. level. If performed carefully, however, this resulted in no substantial increase in E.M.G., in addition to which no tremor was evident. At that point, the patient disclosed that the tremor was provoked by holding an object requiring finger-thumb opposition. The patient was asked in the next session, to attempt holding a pencil using index finger and thumb. E.M.G. readings immediately increased to around 200μV, the arm

jerking strongly. It was observed that the patient could lessen the tremor by touching his right arm with his left hand. This was accompanied by a reversion of E.M.G. activity to baseline levels. The tremor was deliberately induced a second time, and again calmed by the same manoeuvre. Next, the left hand was gradually withdrawn, leaving the right hand still holding the pencil, Mr. F. being instructed to attend to the feedback signal and to keep it as low as possible. He now held the pencil loosely in his right hand. On his being asked to grip the pencil as if writing, the violent tremor restarted immediately. It was reasoned that the word "writing" had perhaps served as a discriminative stimulus for tremor, and so after a rest, Mr. F. was asked to tighten his grip on the pencil slightly, trying to keep the click rate down, and to relax again should the tremor start. This was successful and it appeared that the subject was using the biofeedback signal as a means of monitoring his E.M.G. level and preventing an increase in E.M.G. level from developing, by relaxation. In the subsequent session, the patient succeeded in reducing his E.M.G. level, whilst holding a pencil, from the range 35 - 40μV, to the range 20 - 30μV, with no tremor discernible. Later, he was able to draw circles on paper, with an E.M.G. level of 10 - 20μV. When instructed to write the alphabet, no tremor was visible, and the E.M.G. reflected phasic muscle movements only. One great disappointment to

Mr. F. had been that, owing to his tremor, he was unable to enjoy a pint of beer in his local hostelry owing to his uncontrollable tremor. Mr. F. was therefore asked to place his hand around a half-pint dimpled beer mug, which was placed, empty, on the table. The recorded E.M.G. level was 10μV. He was then asked to move his arm, still grasping the tumbler in a horizontal plane at head height. Latterly, hardly any tremor was evident, and the E.M.G. level associated with this activity was 20μV. On subsequent sessions, a little water was poured in the mug, from which Mr. F. succeeded in drinking, with an associated E.M.G. level of 20 - 30μV, and no tremor. On returning the mug to the table, the E.M.G. rose to 60μV, but this was owing to the phasic muscle movement involved. The E.M.G. level on drinking from the mug fell from 20 to 10μV in a subsequent session, and progress made was maintained between sessions. Shortly thereafter, Mr. F. discontinued attending since the weather was becoming extremely wintry, and, as he relied upon public transport to travel from the other side of town, this was causing him some inconvenience and even pain. The total number of treatment sessions attended was nine, administered approximately twice weekly.

Miss G.

The plan adopted for Miss G's treatment was to

mobilise the arm by using biofeedback to strengthen the voluntary activity of the biceps muscle, thus hopefully increasing the range of movement, and to increase voluntary E.M.G. in abductor pollicis brevis and abductor pollicis longus in order to increase the range of movement in the thumb, and hence facilitate finger to thumb opposition. The Armtest was administered, and recordings of maximum voluntary E.M.G. on contraction of these muscles were taken at the start of the treatment. Over five sessions, with the assistance of feedback, the maximum E.M.G. recorded from the thumb abductor, increased from 220μV to 500μV, and this was accompanied by an increase in the maximum angle of abduction to 65^{O}. At this point, a variation in the exercise was introduced, in that maximum abduction was also measured under conditions of minimum voluntary effort, in order to approximate the normal abduction pattern. Within six sessions, the full range of thumb abduction was associated with an E.M.G. level of only 40μV. The maximum recorded reading attained on abduction rose to 650μV. The E.M.G. readings attained on flexion of the biceps rose from an initial level of 380μV peak to an eventual maximum of 480μV peak. This was accompanied by a substantial, visible increase in the range of movement at the elbow, so much that by treatment session 8, elbow extension was introduced as a supplementary exercise, using the triceps muscle for biofeedback. Within 6 sessions, maximum recorded

triceps E.M.G. rose from 60μV peak to 800μV peak with arm almost fully extended.

Whereas it would have been inappropriate to have administered a second Armtest to Mr. F., who had earlier scored at the maximum Miss G. completed an Armtest following her 14 sessions of treatment. The comparison of pre and post-test scores is given in Table VI(1).

TABLE VI(1)

Pre & Post-Test Armtest Scores: Miss G.
(Impaired Limb)

SCALE:	GRASP	GRIP	PINCH	GROSSMT.	TOTAL
TEST OCCASION					
PRE-TEST	11	2	8	6	27
POST-TEST	16	9	15	6	46

Some improvement was also evident in range of movement at the elbow as measured by the optical goniometer, an increase from 132° to 142°.

DISCUSSION AND CONCLUSIONS

The pilot studies were useful in that they demonstrated the possibility of success in treating an upper extremity impairment of fairly long standing. The previous duration of the impairment may be considered in each case, to have provided a sufficient baseline against which to assess change. The patients studied indicated (a) the possibility of teaching some measure of control over spasticity, which is a common problem in hemiplegia, by E.M.G. biofeedback therapy; and (b) the possibility of enhancing muscle power and range of movement in the hemiplegic upper extremity. The conduct of the study enabled the experimenter to witness the intense effort which the patients, in particular, Miss G., were prepared to expend, an effort which frequently resulted in supplementation by home practice, without biofeedback, of the movement patterns used during treatment: a factor beyond the biofeedback therapist's control, exhortation apart. By comparison of Table VI(1) with Table V(19) supra it can be seen that improvement occurred for Miss G. on three of the four Armtest subscales, and that these correlated significantly with many of the A.D.L. scales described in Chapter 5. A further con-

clusion taken from the study was the need to modify the target muscle, and the goal for that muscle, as treatment progressed and recovery occurred. A rather joyous accompaniment to Miss G's recovery, was her evidently increasing optimism and confidence; as a result perhaps of which, she met, and was soon engaged to be married to a gentleman of similar age to herself, who was a widower. They were subsequently married and went to stay in the West of Scotland. The author does not seek to imply that this is a frequent outcome of E.M.G. biofeedback treatment!

EXPERIMENTS I AND II

PURPOSE

The contradictory findings reported by diverse researchers, and reviewed in Chapter 3, regarding the application of E.M.G. biofeedback to the neuromuscular re-education of the hemiplegic upper limb, required clarification. The methodological flaws inherent in previous work, particularly in relation to the unknown reliability of the outcome measures used, the lack of a credible placebo control treatment, and sometimes, even the lack of blind assessment, needed to be eliminated in the current study. Further, the response of the patient with a dense hemiplegia to E.M.G. biofeedback therapy needed to be determined. Andrew's (1964) results were optimistic in contrast to those of Brudny *et al.* (1976) and Wolf *et al.* (1979). It was decided to investigate, in the first instance, the effects of biofeedback treatment on a dense hemiplegia affecting the upper limb. An experiment was accordingly devised, using the design described by Revusky in which the criterion for inclusion was an initial total score < 5 for the impaired limb, when tested on Armtest. These patients corresponded approximately to the degree of impairment described by Andrews (1964) and

confirmed in subsequent correspondence with him (1978). If anything, the patients were apparently less severely afflicted than were those of Andrews, since all showed some E.M.G. activity on voluntary effort, and some retained some gross movement of the arm. In addition, a control placebo treatment and no-treatment period were incorporated in the experimental design. The control placebo treatment consisted of biofeedback ofskin temperature recorded from a point above the superficial fascia, overlying the palmaris brevis on each hand, the subject being instructed to alter the temperature differential between the impaired and unimpaired hand. Frequently, the initial temperature recorded from the impaired side was up to 4 ^{o}C lower. The placebo treatment was described as being intended to enrich the blood flow to the muscles of the hemiplegic hand. Taub & Emurian (1976) had previously demonstrated that voluntary temperature changes could be achieved independently of movement or isometric muscle contraction, in the upper limb, and the hemiplegic subjects were asked not to, indeed, because of the degree of their hemiplegia, could not use a muscular strategy. Instructions were given to generate heat by thermal imagery. Most subjects could alter the temperature differential in favour of the hemiplegic hand. This success was considered important in generating expectancy of recovery

for the placebo condition.

METHOD

SUBJECTS

Several candidates fulfilling the inclusion criteria described above, were interviewed and tested on Armtest. From these, seven subjects were selected who were sufficiently accessible at least twice per week, for the prolonged period necessary for the study. One patient had a traumatic lesion, another had an initially vascular lesion, exacerbated by subsequent surgical intervention: the remainder were of vascular origin. All subjects were seen at least three months following onset of the hemiplegia and were considered to have stabilised. Some patients were still receiving some form of diversional therapy, occupational or industrial. It was considered unethical to terminate this, the biofeedback treatment being superimposed, and allocation to treatment being randomised. Such a procedure of randomisation vice matching, has been judged acceptable on statistical grounds (Campbell & Stanley, 1966). The mean age of the subjects was 49.7 years, standard deviation 8.9 years. One was female, and six were male. All were right handed, subjects 3, 4 and 6 having a left, the others a right hemiplegia.

MATERIALS

The Armtest, as described in Chapter 4, was administered as the dependent variable. Goniometer measurements as described in that chapter were also taken. The E.M.G. biofeedback equipment used was as for the pilot study described above, except that, since the subjects were seen regularly at different locations, it was decided to dispense with the chart recorder, in favour of direct readings from the panel meter, since the chart recorder was bulky, heavy and vulnerable to damage. For differential temperature training (D.T.T.) a Comark differential thermometer and two thermistor beads, held in position by Scholl corn plasters (to minimise the effect of air currents) and Micropore adhesive tape were used. An adjustment allowed calibration of a needle on the panel meter to a central position. Deviation in either direction indicated a temperature change in favour of that (left or right) hand. The sensitivity of the instrument could be varied from 3 ^{o}C to 100 ^{o}C per full scale deflection. The ranges used for biofeedback, were 3 ^{o}C and 10 ^{o}C. Feedback was visual only, directly from the panel meter.

PROCEDURE

Two experiments were conducted, each subject being assigned to three blocks of time according

to the plan below (Table VI(2). A treatment block consisted of eight treatment sessions, each lasting one hour. It had been intended that each block should cover six weeks: however, owing to the adverse climatic and industrial conditions referred to in Chapter 5, this could not be adhered to strictly. The assessments, apart from the initial qualifying assessment prior to random allocation, were made blind by raters drawn from a pool of six clinical psychologists who had been given training in using the Armtest and the optical goniometer. Subjects were assessed before and after each block of sessions. Following completion of experiment 1, goniometer readings were dropped from the assessment battery as it became evident that gross discrepancies had arisen as between raters, some of whom had not mastered the use of the instrument, even after additional instruction.

Treatment procedure: E.M.G.

The electrodes were, in the first session, placed over the relevant muscle group in the patient's unimpaired limb, and the amplification, range and feedback rate controls set to provide a discriminable feedback signal at a resting level (approximately 60 - 120 clicks/minute). The feedback signal was conveyed through headphones worn by the subject, in order to maximise concentration and minimise distraction. In this way, and by

verbal explanation, the principle of feedback accompanying increases in myoelectric activity was readily conveyed to all patients. All readily understood instructions to achieve increases in the click rate by flexing the biceps, even although for some patients a degree of expressive aphasia was present. The electrodes were then placed over the relevant site in the impaired limb and the patient instructed, verbally and by gesture, to attempt to generate an increase in the feedback signal by flexing or trying to flex the muscle indicated. A process of shaping was adopted, where the gain of the feedback amplifier was set to a level which responded maximally to any slight increase in the myoelectric activity recorded. The gain of the amplifier was progressively reduced as myoelectric activity increased, so that a larger recorded E.M.G. than before was required in order to generate a discriminable change in the feedback signal. The technique of reinforcing approximation to the desired goal is borrowed from the field of operant conditioning where it is known as "shaping". It was found that subjects were prepared to invest considerable effort in attempting to achieve changes in registered E.M.G. activity, and frequent rest pauses were enforced. One problem which arose was that patients would sometimes achieve increases in myoelectric activity

at the electrode site by involving other muscles, e.g. those of the shoulder girdle, over which they retained greater control, rather than by activating the target muscle. An attempt was made to use two feedback machines, one recording activity in the extraneous muscle, with instructions to keep that reading low whilst maximising activity at the target site. This proved unsatisfactory owing to the splitting of attention which this required, bearing in mind the likelihood of some cognitive and attentional deficits consequent to the brain lesion. Subjects responded sufficiently well, however, to reminders, both verbal and gestural, to minimise involvement of muscles remote from the electrode site. Details of electrode placement and E.M.G. readings, taken from the panel meter, were recorded in an experimental notebook for this and each subsequent session. All patients receiving the E.M.G. feedback condition utilised the biceps and triceps sites, and whatever additional sites seemed appropriate. The possibility of averaging E.M.G. activity over each session was considered, but rejected since frequent rest pauses were required. Accordingly, it was decided to record the peak E.M.G. reading obtained for the electrode site for each session, and also the most typical maximum E.M.G. from the same site.

In addition to participating in the E.M.G. feedback sessions, subjects in this and those in

the D.T.T. condition were asked to practise at home either their efforts at muscle activation, or temperature regulation as appropriate.

Treatment procedure: D.T.T.

The subjects undergoing this condition were instructed that they were participating in a trial of an experimental procedure which might conceivably bring about some restoration of function in the upper limb. A thermistor bead from the differential thermometer was placed above the superficial fascia, overlying the palmaris brevis on either hand, and the appropriate full-scale deflection range, 3 ^{o}C or 10 ^{o}C selected according to the initial temperature differential in favour of the unimpaired limb. Initial temperature differences of 1 ^{o} - 4 ^{o}C were commonly found, the hemiplegic hand being noticeably colder to the touch. It was explained that the procedure was intended to train the subject to achieve increases in blood flow to the muscles of the impaired limb. The meter needle was calibrated to the central position, and the subjects given instructions to visualise thermal imagery, as e.g. holding the impaired hand under a warm stream of water from a bath tap, warming the hand in front of a blazing log fire, or, in one case, holding a toddy (hot whisky drink) in a glass. All subjects receiving the temperature feedback condition were

able to achieve temperature change in the desired direction within the first two sessions. Subjects were encouraged to practise at home without the temperature feedback device.

Treatment procedure: No Treatment

Subjects undergoing this condition were told that changes in the function of their impaired limb, occurring as a result of the passage of time, were being monitored.

TABLE VI(2)

Experimental Design: Experiments 1 & 2

EXPERIMENT 1: E.M.G. FEEDBACK VERSUS DIFFERENTIAL TEMPERATURE TRG. (PLACEBO)

	BLOCK 1		BLOCK 2		BLOCK 3	
SUBJECT 1	E.M.G.	ASSESSMENT	E.M.G.	ASSESSMENT	E.M.G.	ASSESSMENT
SUBJECT 2	D.T.T.		E.M.G.		E.M.G.	
SUBJECT 3	D.T.T.		D.T.T.		E.M.G.	
SUBJECT 4	D.T.T.		D.T.T.		D.T.T.	

EXPERIMENT 2: DIFFERENTIAL TEMPERATURE TRG. (PLACEBO) VERSUS NO TREATMENT

	BLOCK 1		BLOCK 2		BLOCK 3	
SUBJECT 4	D.T.T.	ASSESSMENT	D.T.T.	ASSESSMENT	D.T.T.	ASSESSMENT
SUBJECT 5	NO TMT.		D.T.T.		D.T.T.	
SUBJECT 6	NO TMT.		NO TMT.		D.T.T.	
SUBJECT 7	NO TMT.		NO TMT.		NO TMT.	

As can be seen from Table VI(2), the data from subject 4 could be conveniently utilised in making both comparisons. Owing to constraints on time available to the experimenter, patients had to be seen serially. Subject 5 was to have been the last to enter treatment: however, by this time, the data on all other subjects had been collected, and was so lacking in variance that there was no possibility of a significant effect according to the criteria enunciated by Revusky, whatever the results with that

subject might have been; hence the experiment was discontinued and subject 5 not admitted to the treatment conditions.

HYPOTHESES

The hypotheses tested were as follows:

Experiment 1

1. That the sequence of recovery as indicated by Armtest total scores would follow the sequence of introduction of the E.M.G. biofeedback condition.
2. That the rank order of magnitude of recovery as indicated by Armtest total scores would correspond with the rank order of introduction of the E.M.G. feedback condition.

Experiment 2

1. That the sequence of recovery as indicated by Armtest total scores would follow the sequence of introduction of the D.T.T. condition.
2. That the rank order of magnitude of recovery as indicated by Armtest total scores would correspond with the rank order of introduction of the D.T.T. condition.

RESULTS

The results obtained in the periodic assessments made are given in Table VI(3) below.

TABLE VI(3)

Serial Assessments of Impaired Limb in Experiments 1 & 2

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SUBJECT NO.	VARIABLE	PRETEST	RETESTS POST-BLOCK 1	POST-BLOCK 2	POST-BLOCK 3
1	ARMTEST TOTAL	0	0	1	0
	ARM ABDUCTION	0°	0°	0°	10°
	ARM FORWARD RAISE	0°	0°	0°	5°
	ELBOW EXTENSION	0°	0°	0°	0°
2	ARMTEST TOTAL	0	0	0	0
	ARM ABDUCTION	0°	0°	0°	0°
	ARM FORWARD RAISE	0°	35°	40°	0°
	ELBOW EXTENSION	0°	0°	0°	0°
3	ARMTEST TOTAL	4	3	5	6
	ARM ABDUCTION	90°	90°	90°	90°
	ARM FORWARD RAISE	0°	70°	90°	90°
	ELBOW EXTENSION	94°	150°	130°	84°
4	ARMTEST TOTAL	3	0	0	0
	ARM ABDUCTION	39°	37°	42°	25°
	ARM FORWARD RAISE	42°	38°	31°	44°
	ELBOW EXTENSION	131°	144°	145°	35°

5	ARMTEST TOTAL	0	(D I S C O N T I N U E D)		
6	ARMTEST TOTAL	0	0	0	0
7	ARMTEST TOTAL	4	4	4	4

It was unfortunate that the use of the goniometer had to be discontinued owing to discrepancies which had arisen in the manner in which it was used by some raters. This was not foreseen, indeed contrasted with the acceptable reliability coefficient of +0.90 obtained in the reliability study and depicted in Table IV(3). It can be seen from Table VI(3) that the goniometer data in experiment 1 varied rather erratically and widely from one test occasion to another.

TABLE VI(4)

Maximum E.M.G. Readings (μV) From Biceps and Triceps Before and After E.M.G. Feedback Training

SUBJECT	NO. OF SESSIONS	BICEPS		TRICEPS	
		BEFORE	AFTER	BEFORE	AFTER
1	24	4	8	5	8
2	16	40	40	100	100
3	8	100	160	16	100

DISCUSSION AND CONCLUSIONS

As can be seen from Table VI(3) and (4), the results obtained in no way conform to a configuration of recovery which would reflect a significant treatment effect for either E.M.G. or D.T.T. The order of recovery on Armtest for experiment 1 was (3,1), 2,4; and for experiment 2, (7,6,5), 4. Subject 4 actually deteriorated from the pretest level; subject 3 dropped one score point before increasing to an eventual score of 6; and an apparent increase of one point for subject 1 post-block 2 disappeared post-block 3. The predicted order of recovery for experiment 1 was: 1,2,3,4; and for experiment 2: 4,5,6,7. The actual peak E.M.G. readings, depicted in Table VI(4) for subjects 1 to 3, also give no grounds for claiming a sizeable treatment effect. Only subject 3 showed a sizeable increase for any muscle, and that produced only a two point increase over baseline on the Armtest. Thus any improvement bore no relation to number of sessions of E.M.G., nor was it of any demonstrable functional value.

It is worth pausing to note the lack of any demonstrable effect for the placebo condition. This appears to substantiate the conclusion from Taub & Emurian's (1976) paper that gains in temperature as a result of feedback were unrelated to myoelectric

activity in the underlying muscle. The finding also suggests that, at this level of impairment, there may be little need to consider placebo effects. This might allow some economies to be considered in future treatment experimentation with the upper limb of hemiplegic patients suffering this severe degree of impairment. The goniometer data was so variable as to have to be discounted as meaningless.

Thus the results obtained from E.M.G. feedback treatment using the standardised measure, Armtest, as a dependent variable, were totally at variance with the results reported by Andrews (1964), who was working with a population which was, if anything, apparently more severely impaired than that participating in the present study. Three explanations might be advanced for this discrepancy. One might be that the use of subjective, non-standardised outcome measures not administered blind accounted for the disparity between Andrew's and the present results. This, however, seemed unlikely in view of the magnitude of the change which Andrews observed; a degree of change which "brought tears to some patients' eyes" (Andrews, 1964). A second explanation might consist in differences in materials or procedure as between the Andrews and the present study. Since it seems unlikely that a larger number of longer treatment sessions should have been detrimental, it may have been that the

needle electrodes employed in Andrew's study were more sensitive than the surface electrodes employed in experiments 1 and 2. A difference in procedure is an unlikely cause of the differential outcome, since Andrew's description of his method in training the patient was followed in the present study. A third explanation would rest upon a hypothesised dissimilarity between the patients participating in the Andrews and the present study. This point will be elaborated later in this chapter.

It was accordingly decided to conduct a further experiment in order to determine the relative efficacy of surface and needle electrodes in E.M.G. biofeedback treatment of the upper limb. This constituted experiment 3 in the series.

EXPERIMENT III

PURPOSE

Experiment 3 was designed to test the hypothesis that the type of electrode used, and not the feedback procedure itself, was the cause of the negative findings reported earlier. The experiment compared needle electrodes, inserted sub-dermally, with surface electrodes, and in turn with a placebo condition. The experiment was also an attempt to replicate Andrew's reported finding that in seventeen of twenty hemiplegic patients, a five-minute session employing needle electrodes was adequate to re-establish functional control of the upper limb. For the purposes of comparison, patients who had already participated in experiments 1 and 2 were re-selected.

METHOD

SUBJECTS

Six patients who had earlier fulfilled the inclusion criteria for and who had participated in, experiments 1 and 2, were selected. These were subjects 1,2,3,4,6 and 7.

MATERIALS

The Armtest was used as a dependent variable. The equipment used was as for experiments 1 and 2, except that, in addition to surface electrodes,

monopolar needle electrodes approximately 1 cm in length, supplied by Biofeedback Systems Ltd., were employed. A permanent record of myoelectric activity during E.M.G. feedback sessions was obtained by routing the output from the E.M.G. 90 biofeedback amplifier through the 1x/10x amplifier described in the pilot study, to the 1 V input socket of a Devices MX6 chart recorder, running at a chart speed of 25 divisions per 10 seconds. A cine film record was made of each patient's range of arm movement before and after treatment, using a Bumig XL cine camera on Ektachrome type 160B film.

PROCEDURE

Each patient received three experimental conditions: E.M.G. feedback from surface electrodes, E.M.G. feedback from needle electrodes, and temperature feedback (D.T.T.). Patients were assigned randomly to the six possible permutations of treatment order. Electrode placement for the two types of E.M.G. electrodes was selected by palpation, as described in the procedure section of the pilot study reported earlier. The thermistor beads were placed on the palmar surface of the distal phalanx of each middle finger, and secured (not covered) with Micropore tape and Scholl corn plasters. The needle electrodes were inserted by a senior registrar in rehabilitation medicine. E.M.G.

feedback was provided both visually, and aurally by headphone. The remaining details of the feedback procedure and instructions to subjects were as described in the procedure section of experiments 1 and 2, save that the total duration of any one type of feedback was limited to five minutes. The Armtest was administered before and after each experimental condition, in a separate room, and under blind conditions, by one of two clinical psychologists who had received prior training in that assessment technique. Output from the relevant feedback amplifier was continuously recorded during experimental sessions on the MX6 chart recorder.

HYPOTHESIS

The hypothesis tested was that Armtest total scores following E.M.G. feedback using needle electrodes, would differ significantly from baseline levels and from other treatment conditions.

RESULTS

The Armtest scores attained at each successive assessment are tabulated below in Table VI(5). The differences between the means were, by inspection, not significant.

TABLE VI(5)

Armtest Scores: Successive Assessments

SUBJECT	PRETEST	POST-E.M.G.(S)	POST-E.M.G.(N)	POST-D.T.T.
1	0	0	0	0
2	0	0	0	0
3	6	7	6	5
4	0	0	0	0
6	5	7	9	5
7	6	7	5	6
MEAN	2.43	3.00	2.86	2.29

In addition, the maximum readings attained on the relevant feedback variable are presented in Table VI(6).

TABLE VI(6)

E.M.G. & D.T.T.:
Maximum Values Attained

SUBJECT	SITE	E.M.G. SURFACE	E.M.G. NEEDLES	D.T.T. (IMPAIRED SIDE - UNIMPAIRED)
1	BICEPS	19μV	11μV	-0.12 °C
2	BICEPS	40μV	18μV	-0.12 °C
3	BICEPS	90μV	80μV	-0.96 °C
4	BICEPS	22μV	24μV	+0.36 °C
6	BICEPS	20μV	20μV	0
7	ABDUCTORES POLLICIS	10μV	10μV	-0.42 °C

DISCUSSION AND CONCLUSIONS

The E.M.G. readings obtained using surface and needle electrodes should not be expected necessarily to be equal since each type of electrode samples a different population of muscle fibres: surface electrodes summate activity over a wider area, more distally; whereas needle electrodes sample more restricted numbers of fibres adjacent to or transfixed by the electrode. Therefore, it was appropriate to consider the Armtest measure as the dependent or outcome variable. The results portrayed in Table VI(5) starkly contrasted with expectations arising from Andrew's study. There was certainly no evidence of a return to functional use of the limb following a five-minute treatment session, whether utilising surface or needle electrodes, differences in the criterion variable as between the two methods being non-significant; as indeed were comparisons between each in turn and baseline and post-placebo measures. This would tend to support the conclusion that it was not the want of needle electrodes which rendered the E.M.G. feedback treatment, described in experiments 1 and 2, ineffective: rather it seemed that the explanation for the discrepancy between the findings and those of Andrews might lie in some degree of incomparability as between the patients studied by the respective researchers. It is here argued that the

review of the E.M.G. feedback literature presented in Chapter 3 supports the conclusion that E.M.G. feedback treatment is least likely to be effective with severer degrees of hemiplegia afflicting the upper limb; and it has already been demonstrated that Andrew's findings, although widely quoted, appear to represent an anomaly. (An explanation which reconciles these differences will be reserved for the discussion following experiment 4).

Therefore the decision was made to conduct a further trial of E.M.G. feedback, in which a group of patients suffering lesser degrees of hemiplegia, or hemiparesis, affecting the upper limb could be studied: in order to establish whether a lesser initial degree of impairment would conduce to a more positive outcome of E.M.G. biofeedback therapy.

EXPERIMENT IV

PURPOSE

Experiment 4 was intended to test the hypothesis that patients suffering milder degrees of hemiplegia, or hemiparesis in the upper limb, might benefit significantly more from E.M.G. biofeedback than from a placebo treatment. A differential result as compared with experiments 1 and 2 might help to clarify Andrew's findings, in addition to supporting the earlier tentative conclusion from the literature review that the initial degree of impairment might have important prognostic implications for the likely response to E.M.G. biofeedback treatment.

METHOD

SUBJECTS

Four subjects, each scoring on an initial Armtest administration, at above the initial level attained by subjects participating in the experiments reported above took part. Armtest total scores for the impaired upper limb thus exceeded 7 in each case. For three subjects, the hemiplegia was vascular in origin, and for the fourth, was presumed viral. All four subjects were male. One had left hemiparesis (subject 2) and all were right-handed. Three were attending an occupational day centre, whilst a fourth was attending a day

hospital (A.A.H.) for speech therapy. All patients were seen at least one year post-lesion; one was seen at 5 years post-lesion, another at 12 years, and the fourth at 44years post-lesion. The mean age was 54.75 years, s.d. 8.26 years, range 45-66 years.

MATERIALS

The materials and apparatus used were as described for experiments 1 and 2.

PROCEDURE

Subjects were allocated at random, following an initial qualifying Armtest assessment, to one of the treatment combinations in the Revusky design depicted in Table VI(7) below. Where a subject did not receive two blocks of E.M.G. treatment as part of the Revusky design, extra sessions were administered following completion of that design, in order to allow, in addition, a small group study, extending over sixteen E.M.G. biofeedback treatment sessions, partially nested within the Revusky design. Scrutiny of Table VI(7) will clarify the composite experiment conducted.

Although the techniques used in E.M.G. biofeedback training and differential temperature training with subjects participating in experiment 4 were as for experiments 1 and 2, nevertheless the target muscles and tasks allotted for the blocks of

TABLE VI(7)

Experimental Design: Experiment 4
Composite Revusky and Group Design

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5
SUBJECT 1	E.M.G.	E.M.G.	E.M.G.		
SUBJECT 2	D.T.T.	E.M.G.	E.M.G.		
SUBJECT 3	D.T.T.	D.T.T.	E.M.G.	E.M.G.)	
SUBJECT 4	D.T.T.	D.T.T.	D.T.T.	E.M.G.)	E.M.G. (ASSESSMENT)

ASSESSMENT

ASSESSMENT

ASSESSMENT

ASSESSMENT)

E.M.G. feedback sessions, were rather different. Whereas for subjects participating in experiments 1 and 2, the arm had been usually limp and incapable of making other than a few extremely gross movements, the subjects in experiment 4 showed a rather different pattern of impairment. For them, the biceps and triceps muscles had already recovered to some extent; therefore it was towards the movements of the hands and wrist that attention required to be directed. Target muscles therefore included the finger and wrist extensor muscles, and tasks involved not only the maximisation of E.M.G. activity, but also its minimisation when some degree of spasm was likely to supervene. As in the procedures employed with Miss G. and described in the Pilot Study, once a movement had been achieved with maximum muscle activity, the task was next set of achieving a similar range or pattern of movement, utilising the minimum necessary muscle activity, in order to more accurately simulate the normal movement pattern. Sometimes a subject might be able to maintain, for example, finger extension for only a limited period of time before spasm occurred. For such a subject, the training method used was to train the subject to maintain the extension for a slightly longer period, by means of attending to the muscle activity, and reducing it to its lowest level.

With the exceptions noted above, the remaining procedural details were as described in the relevant sections of the procedure for experiments 1 and 2.

HYPOTHESES

The hypotheses tested were as follows:

1. That the sequence of recovery as indicated by Armtest total scores would follow the sequence of introduction of the E.M.G. biofeedback condition.
2. That the rank order of magnitude of recovery as indicated by Armtest total scores would correspond with the rank order of introduction of the E.M.G. biofeedback condition.
3. That myoelectric change in the required direction would differ significantly in comparing subjects before and after sixteen E.M.G. feedback sessions.
4. That Armtest total scores would differ significantly in comparing subjects before and after sixteen E.M.G. feedback sessions.

RESULTS

The results obtained in the periodic assessments made are given in Table VI(8) below.

TABLE VI(8)

Serial Armtest Assessments of Impaired Upper Limb In Experiment 4

SUBJECT NO.	PRETEST	(R E T E S T S)					FOLLOW-UP
		POST-BLOCK 1	POST-BLOCK 2	POST-BLOCK 3	POST-BLOCK 4	POST-BLOCK 5	(1-2½ MONTHS)
1	8	10	15	27	-	-	31
2	24	32	33	35	-	-	33
3	30	29	26	30	34	-	41
4	23	19	17	18	20	19	19

Table VI(9) depicts the pre-treatment and post-treatment E.M.G. maxima recorded from each site for the first two blocks of E.M.G. feedback training, as per the group design indicated by underlining in Table VI(7). It should be noted that subject 2 showed a decrement since control of spasm was the relevant experimental task. Table VI(10) contains the Armtest outcome data for the nested group design.

TABLE VI(9)

E.M.G. Outcome Data by Target Site
Following Two Blocks of E.M.G. Feedback Training

SUBJECT	ELECTRODE SITE (TASK)	PRETEST MAX. (μV)	POST-TEST MAX. (μV)
1	(WRIST EXTENSION) EXTENSOR CARPI ULNARIS EXTENSOR CARPI RADIALIS	20	40
	(FINGER EXTENSION) DORSAL INTEROSSEI 2,3,4	40	120
2	(THUMB ABDUCTION) ABDUCTOR POLLICIS BREVIS ABDUCTOR POLLICIS LONGUS	100	8

TABLE VI(9) CONT.

SUB-JECT	ELECTRODE SITE (TASK)	PRETEST MAX. (μV)	POST-TEST MAX. (μV)
3	(SHOULDER ABDUCTION) DELTOID	200	300
	(THUMB ABDUCTION) ABDUCTOR POLLICIS BREVIS ABDUCTOR POLLICIS LONGUS	10	160
4	(SHOULDER ABDUCTION) DELTOID	120	300
	(FINGER EXTENSION) DORSAL INTEROSSEI 2,3,4	20	40
	(THUMB ABDUCTION) ABDUCTOR POLLICIS BREVIS ABDUCTOR POLLICIS LONGUS	40	60

TABLE VI(10)

Armtest Outcome Data
Following Two Blocks of E.M.G. Feedback Training

SUBJECT	PRETEST	POST-TEST
1	8	15
2	32	35
3	26	34
4	18	19

The significance or otherwise of the results displayed in Tables VI(8) to (10) may be considered in turn. With regard to serial Armtest assessments within the Revusky design, the sequence of improvement prediction (1,2,3,4) was disconfirmed by the improvement seen in subject 2 following his first block of placebo treatment. The sequence of recovery was thus 1=2,3,4. That outcome was therefore not a significant demonstration of the efficacy of E.M.G. biofeedback treatment vis-a-vis the D.T.T. placebo condition. However, in terms of the magnitude of improvement in Armtest scores, the results indicated a significant treatment effect since subject 1, who had received the most feedback therapy, increased his score more than did subject 2, whose score increased more than did that of subject 3, whose score increased more than did that of subject 4, over the three-block Revusky

design. The probability of such a result occurring by chance was $p \leq 0.042$, since the number of permutations of order of magnitude of increase in scores among 4 subjects is 4!

Passing to the small group design, partially nested within the Revusky experiment referred to above, the data portrayed in Table VI(9) were tested for significance by the Wilcoxon matched pairs signed-ranks test. This non-parametric test was chosen since the number of observations was small. The predicted direction of change in myoelectric activity was in a positive direction for subjects 1,3 and 4, and in the negative for subject 2, who was taught to <u>decrease</u> myoelectric activity in order to prevent spasm. Each prediction was confirmed, with $p < .005$ in a one-tailed test.

The group outcome data on Armtest as depicted in Table VI(10) did not attain acceptable significance levels by either the Wilcoxon or the binominal signs tests.

DISCUSSION AND CONCLUSIONS

The results reported above, are rather more favourable to E.M.G. biofeedback, than were those obtained in experiments 1,2 and 3; although not uniformly so. One of two predictions regarding the Revusky design was confirmed, namely that in respect of the magnitude of recovery. The E.M.G. data for the small group study indicated a significant treatment effect, although this was not apparent for the Armtest data. A follow-up assessment did however, indicate that the two subjects who did increase their Armtest scores substantially following two blocks of E.M.G. biofeedback, maintained, even bettered their performance at follow-up. These results, whilst not conclusive, are suggestive of some beneficial treatment effect of E.M.G. biofeedback training, apart from a placebo response. The results obtained may be contrasted with those in experiments 1,2 and 3, wherein subjects suffering a dense hemiplegia participated. That comparison calls to mind the more general conclusion reached by Granger et al. (1977) namely of a positive relationship between functional status on admission and progress made during rehabilitation. Perhaps future experimentation may clarify that E.M.G. feedback for the upper limb is more effective for treatment

of hemiparesis rather than of hemiplegia. The distinction between these might be expected to depend on factors such as location of lesion, and mass of brain tissue destroyed. It may be said that gross differences in level of motivation were not evident as between subjects both within and across the experiments reported above: indeed one most distressing aspect of conducting this research was to witness the extremes of effort which patients were prepared to invest in a treatment which ultimately was to prove of little benefit to them.

The problem would seem to remain, however, of reconciling Andrew's (1964) results with those reported in this thesis. It will be recalled that Andrews reported achieving substantial functional recovery in patients' densely hemiplegic upper limbs within a five-minute feedback period. An explanation for this apparently discrepant finding may be afforded by the hypothesis that Andrew's subjects were qualitatively different from the usual densely hemiplegic patient, in the sense of suffering primarily from an <u>apraxic</u> disorder rather than a lesion of the motor cortex per se: that is a higher-order associative deficit which might be expected more rapidly to respond to the provision of an artificial, external feedback loop. The provision of external feedback would

seem particularly important for such patients who had perhaps been hitherto impeded in their recovery by some loss of kinaesthetic and proprioceptive information. Where the primary motor cortex and final common pathway were spared, an effective alternative cognitive strategy might quickly be found to instigate purposeful use of the upper limb.

A more proportioned view of the likely differential efficacy of E.M.G. feedback therapy is to be viewed as desirable and beneficial in directing a treatment which is costly in time and equipment, at patients who are most likely to benefit from it. Perhaps the time has arrived when a more realistic appraisal of its efficacy may be undertaken, since the first flush of enthsiasm over feasibility of basing treatments upon biofeedback principles, in this and other fields, may now have abated.

On a practical level, the next logical step would seem a large scale trial of E.M.G. feedback treatment for the hemiplegic upper limb, without a placebo comparison but perhaps incorporating a within-subject no-treatment period. Because of the investment of time involved in treating each patient, and because of the need to avoid therapist-specific effects, the trial might best be conducted on a multi-centre basis. The model of standardised

assessments, of proven reliability, and administered blind, afforded by the experiments reported earlier would be appropriate for such an enterprise. Subjects might be selected to vary in respect of a number of parameters considered relevant to outcome, with a view to conducting a retrospective discriminant function analysis to permit future pre-selection of likely responders to treatment. Pre-treatment Armtest score might be one such parameter; indeed the experimentation reported above would seem to support its candidacy. Degrees of sensory impairment, lesion site and brain mass affected are additional potentially relevant correlates of treatment response. The means of discerning these accurately, however, remain to some extent unsatisfactory. In particular, the writer is unaware of any standardised measure of proprioception of known, satisfactory reliability. Perhaps some research effort might fruitfully be directed towards developing basic assessment techniques in physical therapy, on psychometric principles. The psychophysical procedures of Weber (1834) and Fechner (1966) might well find some new application in this area.

A more fundamental question concerns the processes underlying biofeedback. There is little factual knowledge available regarding the under-

lying brain processes whereby biofeedback results are achieved, although there are diverse theoretical explanations available (see Chapters 1 & 3). Consideration of this subject, however, will be reserved for the general discussion in the following chapter.

CHAPTER SEVEN

GENERAL DISCUSSION

Following the specific discussion and conclusions offered in previous chapters regarding the research done, the time is now appropriate to consider the general implications and applications of the work conducted. The thesis has made a contribution in each of the three areas, and it is appropriate to consider each of these in turn.

The development of the Armtest, described in Chapter 4, is seen as significant in two principal respects. First, the test is a standardised behavioural test of upper extremity function, which has a high reliability and a demonstrated validity vis-a-vis an Activities of Daily Living measure. For this reason it is not only an appropriate outcome measure to employ in evaluating E.M.G. biofeedback as reported earlier in this thesis: it is of potential use in the evaluation of treatments, both pharmacological and physiotherapeutic, in physical rehabilitation. This is seen as particularly apposite, since, as stated in Chapter 1, most treatment procedures in physical rehabilitation currently lack an empirically demonstrated validity. Thus the Armtest may find an application in the construction of an applied science of physical therapy. In the

course of reviewing the literature for, and in planning, the experimental work described in this thesis, it became apparent that there was also a lack of any standardised, reliable and valid measure of such functions as proprioception, sensation and gait. This conveniently introduces the second respect in which the development of the Armtest is seen as significant: namely, that it constitutes the hitherto unimagined, and yet potentially highly fruitful application of psychometric expertise and techniques to the evaluation of physical disability. The concepts of standardisation, reliability and validity are directly transferable from the realm of mental testing to that of disability evaluation and are available, now, as a basis for constructing a truly applied science of physical rehabilitation, both in the scientific description of individuals and in conducting controlled trials of treatments. Such a development might be expected to contribute to a further increase in the relative professional standing of physiotherapy, at a time when one senses an emergent self-confidence in that group.

Apart from its obvious application as a standardised method for use in evaluating treatment outcome, certain other uses can be discerned for the Armtest. Patients participating in experiments 1 and 2 and in experiment 4, were

chosen on the basis of their initial Armtest scores: and only in experiment 4 where the minimum initial Armtest total score was eight, was a significant treatment effect for E.M.G. biofeedback found. The question therefore arises as to whether the Armtest may prove to be of use as a predictor of likely response to biofeedback therapy. However, one would certainly require further research in order to establish whether this were true.

The potential merit of the Armtest as a descriptor of a patient population must also be considered. One might envisage the use of Armtest in a survey, in order to discern the pattern of upper extremity dysfunction in a particular diagnostic group. Serial evaluation using the Armtest might further serve to monitor either progress or deterioration over time, as for instance in multiple schlerosis.

Data were presented in Chapter 5, to indicate that the Armtest was correlated with certain sub-scales of the Guttman-scaled Activities of Daily Living test. A further development which is planned for the near future, is the integration of certain of the Armtest items, into the Guttman-scaled A.D.L. This would enable predictions regarding performance in a wide variety of Activities of Daily Living tasks to be predicted

on the basis of an extremely rapid test administration, since average time taken to administer the Armtest is approximately 10 minutes.

If the Armtest is seen as a contribution towards assessment and evaluation in physiotherapy, then the development of the Activities of Daily Living measure is seen as an equally important contribution to the practice of occupational therapy. In physical rehabilitation, occupational therapy has advanced beyond merely diversional therapy and extends to the teaching of and assessment of competence in A.D.L. The observational and training role, indeed, strikes parallels with the activities of the clinical psychologist of a broadly behavioural persuasion, and the scope for mutual enrichment of the two professions is as yet untapped. Procedures and techniques, particularly metric and statistical, originally developed by clinical psychologists, may find ready application in occupational therapy, whilst the psychologist, naive in the intensive study and functional training of the disabled individual, may here learn something to his advantage. Indeed, occupational therapy has perhaps closer affinities with clinical psychology than has any other remedial profession. The outcome of the collaborative assessment exercise described in Chapter 5 was therefore particularly gratifying. First, one has identified a new basis

for grouping Activities of Daily Living which may have extremely important implications for the conduct of functional retraining: in that A.D.L. has been grouped according to similarities in underlying function. This therefore at the same time affords a more rational basis for the integration of physiotherapeutic and occupational therapeutic work with the same patient, and further, may permit a more simplified and less fragmented approach to the teaching of A.D.L. One eagerly anticipates the application of this correlational approach to A.D.L. to other groups of patients, as e.g. multiple schlerosis, rheumatoid arthritis, amputees, even the psychiatrically ill and the mentally handicapped. It is probable that different groupings of items would emerge for some of these groups, and could be used as an aid to identifying the particular dimensions of difficulty in performing Activities of Daily Living within each group. The second major advance is held to be the very considerable abbreviation of A.D.L. testing time achieved without loss of comprehensive assessment, by introduction of the elegant technique of Guttman scaling. Whilst the relatively small size of the sample studied is admitted, a further replicative study is currently in progress and a reliability study is planned to follow. An average saving in testing of more than 50% of test items represents a thoroughly practical application of statistics to

occupational therapy. A particularly important advantage of the Guttman scales identified, is that predictions are enabled regarding aids required, and the likelihood of a patient being likely to benefit from a particular aid, if supplied. In the current tense international situation, one must regretfully also be mindful that a rapid means of classifying individuals by dependency and of determining such needs in the aftermath of a war producing potentially large numbers of casualties, would be of substantial humanitarian and practical benefit in speeding rehabilitation and maximising the resumption of independence: although one hopes that such a contingency may not arise.

In conclusion the Guttman-scaled A.D.L. presented as a contribution towards a more scientifically oriented occupational therapy. That profession stands at a crossroads in its development, with the organisation of training courses at colleges of higher education. The provision of a more scientific basis for what have hitherto been craft or skill activities is seen as enabling more rapid progress to be made in expanding the profession's effectiveness in contributing to patients' wellbeing, and in enhancing its acceptance as a profession of equal standing with others involved in the task of physical rehabilitation.

The E.M.G. biofeedback research reported in this thesis, will have been worthwhile if it serves to call attention to the difficulty encountered in replicating Andrew's spectacular (1964) results. The Andrews study, although cited in virtually every research paper on the topic, appears more and more to represent an anomalous finding, which may have given rise to false hopes and the fruitless investment of one knows not how many hours of research and clinical time, as it may have resulted in an enthusiastic over-estimation of the likely effectiveness of E.M.G. feedback, particularly in cases of dense hemiplegia. The finding in experiment 3, that there appeared for that group to be no particular advantage in using needle electrodes with that level of impairment, may save future patients some unnecessary pain, in addition to opening E.M.G. biofeedback training to non-medical practitioners, who may use surface electrodes. The results obtained in experiment 4 are, however, of most interest, since they appear to suggest that E.M.G. biofeedback of the upper extremity in hemiplegia, is likely to be more successful amongst patients suffering degrees of hemiparesis, that is those who have retained or regained some functional use of the upper limb. The finding that it was possible to facilitate

some recovery of function in the hand of patients who had ceased to receive other varities of therapy since they were considered to have reached a plateau of recovery, should be sufficient to encourage enthusiastic prosecution of this avenue of treatment, since the function of the arm and hand is, as indicated by the correlational exercise reported in Chapter 5, overwhelmingly dominant in determining competency in Activities of Daily Living, and yet is normally considered to have a poor potential for recovery under conventional treatment (Wahle, 1973). In combining the results of the presently reported studies with published reports of earlier work, reviewed in Chapter 2, it would appear reasonable to conclude that E.M.G. biofeedback may, in some cases, generate a treatment, as distinct from a placebo effect when applied to the neuromuscular re-training of the upper limb. The next logical development would appear to be the undertaking of a large-scale trial of E.M.G. biofeedback of the upper limb incorporating hemiplegic patients varying in respect of a number of parameters thought relevant to outcome. Such parameters might include functional status of the limb, and the Armtest would seem a particularly appropriate measure in view of both its established metric properties of reliability, and its concurrent validity in relation to the Guttman-scale A.D.L. test

reported earlier. Other parameters which might be relevant might include chronicity of the disability, degrees of spasticity or apraxia, of impairment of sensation and of proprioception; although in the case of the latter two, some elementary test development work should, in the opinion of the author, be first undertaken. In view of the large investment of time required in administering E.M.G. biofeedback treatment, and in order to ensure a representative sample of patients and of experimenters, it is suggested that such a proposed treatment trial should be conducted on a multi-centre basis.

Despite the current enthusiasm for biofeedback treatments, little is known of the brain processes whereby such treatment effects are achieved, and this question is particularly intriguing in the case of E.M.G. biofeedback in neuromuscular retraining of patients with brain lesions. The reason for this, is that in biofeedback procedures conducted with intact individuals, numerous cognitive mediators, or strategies are readily available as a vehicle for achieving physiological changes in the desired direction: as for example in achieving increases in heart rate by imagining a frightening scene. These alternative cognitive mediators may not be so readily available to the hemiplegic patient who has had some of his sensorimotor patterns destroyed. The mechanism

of the gradual reconstruction of, or compensation for these patterns merits study in its own right, and in this context the author wishes to describe two methodologies which might, if recruited, cast some light upon this topic. The Russian psychologist Luria (1978) described a method of studying cortical activity by correlating action potentials simultaneously recorded from as many as 150 sites over the brain, on special multi-channel apparatus. Luria reported a finding that the pattern of intercorrelation observed changed according to particular types of mental activity. It would be of substantial interest to conduct such recordings during E.M.G. feedback training sessions with the hemiplegic. An alternative, or complementary solution to the question as to how to observe patterns and sites of activity during E.M.G. biofeedback of hemiplegic patients may be discerned in the description by Eccles (1979) of a technique for recording changes in blood flow in the cortical vessels during mental tasks, by radio-tracer techniques, whereby radio-Xenon is introduced into the cerebral circulation. A considerable increase in circulation to the frontal lobes was found when a subject thought of hand movements without moving the hand: and when hand movements were actually carried out there was a large increase over the hand motor

area. With a mild thumb stimulus there was an increase above resting level in the precentral flows close the thumb area.

It seems truly surprising that no researcher has yet thought to apply such methods to the study of brain processes accompanying participation in biofeedback. Such a study, in relation to the task and patient population to which this thesis relates would surely add a new dimension to our understanding of this but small aspect of nature's infinite mystery.

CHAPTER EIGHT

CONCLUSIONS

1. The Upper Extremity Function Test was found to be a reliable measure of upper extremity function suited for use in treatment evaluation.

2. The simplification and Guttman structure by which the U.E.F.T. was developed into the Armtest yielded significant savings without a corresponding reduction in its suitability for the above purpose.

3. Certain "objective" measures of upper extremity function investigated (Isodyne, grip dynamometer) were found not to be sufficiently reliable for the contemplated treatment evaluation.

4. The Armtest was felt to be potentially suitable for evaluation of other rehabilitative procedures.

5. Armtest was shown to have concurrent validity with a measure of activities of daily living.

6. Following further research, Armtest was felt to hold promise of predicting competence in certain activities of daily living.

7. The possibility of producing a test of A.D.L. for hemiplegia following stroke based upon statistical, functional groupings of items was demonstrated.

8. The functional groupings of items so identified were found to relate principally to upper extremity function, thus further emphasising the importance of developing effective treatments for the upper limb in hemiplegia.

9. The possibility of abbreviating A.D.L. testing by incorporating the majority of A.D.L. items into twelve Guttman scales was demonstrated.

10. The groupings of items so identified were considered to have implications for the structuring of treatment, and for the prescription of aids.

11. The application of the same correlational and scaling exercise to other diagnostic groups of patients was considered a logical future development.

12. E.M.G. biofeedback of the upper limb failed to achieve a significant treatment effect for the severely impaired hemiplegic patients studied.

13. A partial replication of the Andrews (1964) study failed to demonstrate a significant treatment effect for E.M.G. biofeedback administered in five-minute treatment sessions to six severely impaired hemiplegics.

14. The substitution of needle for surface electrodes administered in the manner described by Andrews (1964) did not alter the negative findings with the severely impaired patients.

15. In evaluating E.M.G. biofeedback with less severely impaired, or hemiparetic patients a significant treatment effect was found in the magnitude of recovery as measured by the Armtest, and also for the direction of change in E.M.G. readings from the muscles concerned.

16. It appeared therefore, that functional status of the upper limb prior to entry into E.M.G. biofeedback treatment discriminated crudely regarding likely outcome.

17. It was considered desirable that further research into the efficacy of E.M.G. biofeedback in neuromuscular retraining of the upper limb of hemiplegics be conducted on a large scale, perhaps multi-centre basis in order to detect predictors of outcome, and hopefully to substantiate that tentatively suggested above.

18. Concurrent recordings of cerebral circulation made during such biofeedback training should be studied in order to aid our understanding of the underlying brain processes.

REFERENCES

ANDREWS, J.M. Neuromuscular re-education of the hemiplegic with the aid of the electromyograph. Archives of Physical Medicine and Rehabilitation 1964, 45, 530-532.

ANDREWS, J.M. Personal communication, 1978.

BARLOW, D.H., BLANCHARD, E.B., HAYES, S.C., & EPSTEIN, L.H. Single case designs and clinical biofeedback experimentation. Biofeedback and Self-Regulation 1977, 2, 221-239.

BASMAJIAN, J.V. Control and training of individual motor units. Science 1963, 141, 440-441.

BASMAJIAN, J.V., KUKULKA, C.G., NARAYAN, M.G., & TAKEBE, K. Biofeedback treatment of footdrop after stroke compared with standard rehabilitation technique. Effects on voluntary control and strength. Archives of Physical Medicine and Rehabilitation, 1975, 56, 231-236.

BENSON, H., SHAPIRO, D., TURSKY, B., & SCHWARZ, G.E. Decreased systolic blood pressure through operant conditioning techniques in patients with essential hypertension. Science 1971, 173, 740-742.

BIGLAND, B., & LIPPOLD, O.C.J. The relation between force velocity and integrated electrical activity in human muscles. Journal of Physiology 1954, 123, 214-224.

BJORKLUND, A., & STENEVI, U. Growth of central catecholamine neurons into smooth muscle grafts in the rat mesencephalon. Brain Research 1971, 31, 1-20.

BLACK, A.H., COTT, A., & PAVLOSKI, R. The operant learning theory approach to biofeedback training in: Schwarz, G.E., & Beatty, J. (eds) Biofeedback Theory and Research. New York: Academic Press, 1977 (89-127).

BLANCHARD, E.B., & YOUNG, L.D. Clinical applications of biofeedback training. Archives of General Psychiatry 1974, 30, 573-589.

BOBATH, B. Adult Hemiplegia: Evaluation and Treatment London: Heinemann Medical, 1970.

BOOKER, H.E., RUBOW, R.T., & COLEMAN, P.J. Simplified feedback in neuromuscular retraining: An automated approach using electromyographic signals. Archives of Physical Medicine and Rehabilitation 1969, 50, 621-625.

BOURESTOM, N.C., & HOWARD, M.T. Behavioural correlates of recovery of self-care in hemiplegic patients. Archives of Physical Medicine and Rehabilitation 1968, 49, 449-454.

BROADBENT, D.E. The Cognitive Difficulties Questionnaire. In preparation, 1979.

BROCKLEHURST, J.C. Medical, social & psychological aspects of stroke: Final Report. Dept. of Geriatric Medicine, University of Manchester, 1978.

BRODAL, A. Self observations and neuro-anatomical consideration after a stroke. Brain 1973, 96, 675-694.

BRUDNY, J., KOREIN, J., LEVIDOW, L., GRYNBAUM, B.B., LIBERMAN, A., & FRIEDMANN, L.W. Sensory feedback therapy as a modality of treatment in central nervous system disorders of voluntary movement. Neurology 1974, 24, 925-932.

BRUDNY, J., KOREIN, J., GRYNBAUM, B.B., FRIEDMANN, L.W., WEINSTEIN, S., SACHS-FRANKEL, G., & BELANDRES, P.V. E.M.G. feedback therapy: Review of treatment of 114 patients. Archives of Physical Medicine and Rehabilitation 1976, 57, 55-61

BRUNNSTRÖM, S. Associated reactions of the upper extremity in adult patients with hemiplegia. Physical Therapy Review 1956, 35, 4.

BRUNNSTRÖM, S. Motor testing procedures in hemiplegia: based on sequential recovery stages. Physical Therapy 1966, 46, 357-375.

BRUNNSTRÖM, S. Movement Therapy in Hemiplegia. New York: Harper Row, 1970.

BUCHWALD, E. Physical Rehabilitation for Daily Living. New York: McGraw-Hill, 1952.

BUDZYNSKI, T., STOYVA, J., & ADLER, C. Feedback-induced muscle relaxation: application to tension headache. Journal of Behaviour Therapy and Experimental Psychiatry 1970, 1, 205-211.

CAMPBELL, D.T., & STANLEY, J.C. Experimental and Quasi-experimental Designs for Research. Chicago: Rand McNally, 1966.

CARROLL, D. The disability in hemiplegia caused by cerebrovascular disease: Serial studies of 98 cases. Journal of Chronic Diseases 1962, 15, 179-188.

CARROLL, D. A quantitative test of upper extremity function. Journal of Chronic Diseases 1965, 18, 479-491.

CARROLL, D. Hand function in hemiplegia. Journal of Chronic Diseases 1965a, 18, 493-500.

CHOMSKY, N. Review of B.F. Skinner, Verbal Behavior. Language 1959, 35, 26-58.

COCHRANE, A.L. Effectiveness and Efficiency. Random Reflections on Health Services. London: Nuffield Provincial Hospitals Trust, 1972.

DE SOUZA, L.H., LANGTON HEWER, R., & MILLER, S. Functional assessment of the recovery of arm control in hemiplegic patients. Paper presented at 3rd Scientific Meeting, The Society for Research in Rehabilitation, Newcastle-upon-Tyne, 1979.

DONALDSON, S.W., WAGNER, C.C., & GRESHAM, G.E. Unified A.D.L. assessment form. Archives of Physical Medicine and Rehabilitation 1973, 54, 175-179.

DUBO, H.I.C., PEAT, M., WINTER, D.A., QUANBURY, A.O., HOBSON, D.A., STEINKE, T., & REIMER, G. Electromyographic temporal analysis of gait: Normal human locomotion. Archives of Physical Medicine and Rehabilitation 1976, 57, 415-420.

ECCLES, J.C. The Human Psyche. Berlin: Springer, in press, 1979.

EISENSON, J. Examining for Aphasia. New York: Psychological Corporation, 1954.

ENGEL-SITTENFELD, P. Biofeedback in the treatment of neuromuscular disorders in: Beatty, J., & Legewie, H. (eds) Biofeedback and Behavior. New York: Plenum, 1977 (427-438).

FECHNER, G. Elements of Psychophysics: translation by Adler, H.E. New York: Holt, Rinehart & Winston, 1966.

FEIGENSON, J.S., McCARTHY, M.L., GREENBERG, S.D., & FEIGENSON, W.D. Factors influencing outcome and length of stay in a stroke rehabilitation unit. Stroke 1977, 8, 657-666.

FINGER, S., WALBRAN, B., & STEIN, D.G. Brain damage and behavioural recovery: serial lesion phenomena. Brain Research 1973, 63, 1-18.

FISH, D., MAYER, N., & HERMAN, R. Letter to the Editor: Biofeedback. Archives of Physical Medicine and Rehabilitation 1976, 57, 152.

FREYTAG, E. Fatal hypertensive intracerebral haematomas: A survey of the pathological anatomy of 393 cases. Journal of Neurology Neurosurgery and Psychiatry 1968, 31, 616.

GANNON, L., & STERNBACH, R.A. Alpha enhancement as a treatment for pain - a case study. Journal of Behaviour Therapy and Experimental Psychiatry 1971, 2, 209-213.

GOFF, B. The application of recent advances in neurophysiology to Miss M. Rood's concept of neuromuscular facilitation. Physiotherapy 1969, 55, 409-419.

GOODENOUGH, W.H. A technique for scale analysis. Educational and Psychological Measurement 1944, 4, 179-190.

GOODKIN, R., & DILLER, R. Reliability among physical therapists in diagnosis and treatment of gait deviations in hemiplegics. Perceptual and Motor Skills 1973, 37, 727-734.

GRACANIN, F., KRALJ, A., & REBERSEK, S. Advanced version of the Ljubljana Functional Electronic Peroneal Brace with Walking-Rate-Controlled Tetanization in: Proceedings of the Third International Symposium on the External Control of Human Extremities. Dubrovnik, 1970 (487-493).

GRANGER, C.V., SHERWOOD, C.C., & GREER, D.S. Functional status measures in a comprehensive stroke care program. Archives of Physical Medicine and Rehabilitation 1977, 58, 555-561.

GRAY, C.L. E.M.G. biofeedback and relaxation training for tension headaches. Unpublished M.Phil. Thesis. University of Edinburgh, 1977.

GUTTMAN, L. The quantification of a class of attributes: a theory and method of scale construction in: Horst, P. (ed.) The Prediction of Personal Adjustment. New York: Social Science Research Council, 1941 (318-343).

HALSTEAD, L., & HARTLEY, R.B. Time Care Profile: An evaluation of a new method of assessing A.D.L. dependence. Archives of Physical Medicine and Rehabilitation 1975, 56, 110-115.

HARDYCK, C.D., PETRINOVICH, L.F., & ELLSWORTH, D.W. Feedback of speech muscle activity during silent reading. Rapid extinction. Science 1966, 154, 1467-1468.

HARRIS, A. Handicapped and Impaired in Great Britain Part I. London: H.M.S.O., 1971.

HERSEN, M., & BARLOW, D.H. Single-case Experimental Designs: Strategies for Studying Behavior Change. New York: Pergamon, 1976.

HUGHLINGS JACKSON, J. On the nature of the duality of the brain (1874) in: Selected Writings of John Hughlings Jackson, vol. 2. London: Hodder & Stoughton, 1932 (45-75).

INGLIS, J., CAMPBELL, D., & DONALD, W. E.M.G. biofeedback & neuromuscular rehabilitation. Canadian Journal of the Behavioral Sciences 1976, 8, 299-323.

JACOBSON, E. Progressive Relaxation. Chicago: University of Chicago Press, 1938.

JOHNSON, H.E., & GARTON, W.H. Muscle re-education in hemiplegia by use of electromyographic device. Archives of Physical Medicine and Rehabilitation 1973, 54, 320-325.

KATZ, S., DOWNS, T.D., CASH, H.R., & GROTZ, R.C. Progress in development of the Index of A.D.L. Gerontologist 1970, 10, 20-30.

KAZDIN, A.E. Statistical analyses for single-case experimental designs in: Hersen, M., & Barlow, D.H. Single-case Experimental Designs. New York: Pergamon, 1976 (265-316).

KNOTT, M. Introduction to and philosophy of neuromuscular facilitation. Physiotherapy 1967, 53 1-2.

KNOTT, M., & VOSS, D.E. Proprioceptive neuromuscular facilitation. New York: Harper Row, 1973.

KÖHLER, W. The Mentality of Apes. New York: Harcourt Brace, 1925.

KRATOCHWILL, T.R. Single Subject Research. New York: Academic Press, 1978.

LANG, P.J., & TWENTYMAN, C.T. Learning to control heart rate: Effects of varying incentive and criterion of success on task performance. Psychophysiology 1976, 13, 378-385.

LANGTON HEWER, R. Operational Policy for Stroke Unit, Frenchay Hospital. The Stroke Unit, Frenchay Hospital, 1974.

LAVIGNE, J. Hemiplegia sensorimotor assessment form. Physical Therapy 1974, 54, 128-134.

LAWTON, E.B. Activities of Daily Living for Physical Rehabilitation. New York: McGraw-Hill, 1963.

LAWTON, M.P., & BRODY, E.M. Assessment of older people: self-maintaining and instrumental A.D.L. Gerontologist 1969, 9, 179-186.

LEAF, W.B., & GAARDER, K.R. A simplified electromyograph feedback apparatus for relaxation training. Journal of Behaviour Therapy and Experimental Psychiatry 1971, 2, 39-43.

LEE, K-H., HILL, E., JOHNSTON, R., & SMIEHOROWSKI, T. Myofeedback for muscle retraining in hemiplegic patients. Archives of Physical Medicine and Rehabilitation 1976, 57, 588-591.

LENIHAN, J. Why buy junk? Evaluation of commercially available equipment. Paper presented at 3rd Scientific Meeting, The Society for Research in Rehabilitation, Newcastle-upon-Tyne, 1979.

LINCOLN, N. Personal communication, 1979.

LINCOLN, N., & LEADBITTER, D. Assessment of motor function in stroke patients. Physiotherapy 1979, 65, 48-51.

LURIA, A.R. Restoration of Function after Brain Injury: translation by Haigh, B. London: Pergamon, 1963.

LURIA, A.R. The Working Brain: translation by Haigh, B. Harmondsworth: Penguin, 1978.

MAHONEY, F.I., & BARTHEL, D.W. Functional evaluation: The Barthel Index. Maryland State Medical Journal 1965, 14, 61-65.

MALMO, R.B. Anxiety and behavioural arousal. Psychological Review 1957, 64, 276-287.

MARINACCI, A.A. Clinical Electromyography. Los Angeles: San Lucas Press, 1955.

MARINACCI, A.A., & HORANDE, M. Electromyogram in neuromuscular reeducation. Bulletin of the Los Angeles Neurological Society 1960, 25, 57-71.

MATHER, H.G., PEARSON, N.G., READ, K.L.Q., SHAW, D.B., STEED, G.R., THORNE, M.G., JONE, S., GUERRIER, C.J., ERAVT, C.D., McHUGH, P.M., CHOWDHURY, N.R., JAFARY, M.H., & WALLACE, T.J. Acute myocardial infarction: home and hospital treatment. British Medical Journal 1971, 3, 334-338.

McCLELLAND, D.C. The Achieving Society. Princeton Van Nostrand, 1961.

McFIE, J. The effects of hemispherectomy on intellectual functioning in cases of infantile hemiplegia. Journal of Neurology Neurosurgery and Psychiatry 1961, 24, 240-249.

MILLER, G.A., GALANTER, E., & PRIBRAM, K.H. Plans and the Structure of Behavior. New York: Holt Rinehart & Winston, 1960.

MILLER, N.E. Learning of visceral and glandular responses. Science 1969, 163, 434-445.

MILLER, N.E., & DWORKIN, B.R. Visceral learning: Recent difficulties with curarised rats and significant problems for human research in: Obrist, P.A., Black, A.H., Brener, J., & Di Cara, L.V. (eds) Cardiovascular Psychophysiology. Chicago: Aldine, 1974 (312-331).

MILLER, N.E., & DWORKIN, B.R. Critical issues in therapeutic applications of biofeedback in: Schwarz, G.E., & Beatty, J. (eds) Biofeedback Theory and Research. New York: Academic Press, 1977 (129-161).

MROCZEK, N., HALPERN, D., & McHUGH, R. Electromyographic feedback and physical therapy for neuromuscular retraining in hemiplegia. Archives of Physical Medicine and Rehabilitation 1978, 59, 258-267.

NEISSER, U. Cognitive Psychology. New York: Appleton-Century-Crofts, 1967.

NETLEY, C. Dichotic listening performance of hemispherectomized patients. Neuropsychologia 1972, 10, 233-240.

NEWELL, A., SHAW, J.C., & SIMON, H.A. Elements of a theory of human problem solving. Psychological Review 1958, 65, 151-166.

NIE, N.H., HULL, C.H., JENKINS, J.G., STEINBRENNER, K., & BENT, D.H. Statistical Package for the Social Sciences. (2nd edn). New York: McGraw-Hill, 1975.

OBRADOR, A.S. Cerebral localisation and organization in: Schaltenbrand, G. & Woolsey, C.N. (eds) Cerebral Localisation and Organisation. Madison: University of Wisconsin Press, 1964: cited in WALSH, K.W. (1978) infra p.260.

OLBRICH, R. Reaction time in brain damaged and normal subjects to variable preparatory intervals. Journal of Nervous and Mental Diseases 1972, 155, 356-362.

PORCH, B.E. Porch Index of Communicative Ability. California: Consulting Psychologists Press, 1967.

POWELL, B.R., DILLER, L., & GRYNBAUM, B. Rehabilitation performance and adjustment in stroke patients: a study of social class factors. Genetic Psychology Monographs 1976, 93, 287-352.

RASKIN, M., JOHNSON, G., & RONDESTVEDT, J.W. Chronic anxiety treated by feedback-induced muscle relaxation. Archives of General Psychiatry 1973, 28, 263-267.

REVUSKY, S.H. Some statistical treatments compatible with individual organism methodology. Journal of Experimental Analysis of Behavior 1967, 10, 319-330.

SCHOENING, H.A., & IVERSEN, I.A. Numerical scoring of self-care status. Archives of Physical Medicine and Rehabilitation 1968, 49, 221-229.

SKINNER, B.F. The Behavior of Organisms. New York: Appleton-Century-Crofts, 1938.

SKINNER, B.F. Science and Human Behavior. New York: Macmillan, 1953.

SMITH, A. Neuropsychological testing in neurological disorders in: Friedlander, W.J. (ed.) Advances in Neurology. New York: Raven Press, 1975 (49-110).

STEIN, D., ROSEN, J.J., & BUTTERS, N. Plasticity and Recovery of Function in the Central Nervous System. New York: Academic Press, 1974.

STICHBURY, J.C. Assessment of disability following severe head injury. Physiotherapy 1975, 61, 268-272.

TAKEBE, K., & BASMAJIAN, J.V. Gait analysis in stroke patients to assess treatments of foot drop. Archives of Physical Medicine and Rehabilitation 1976, 57, 305-310.

TAUB, E., & EMURIAN, C.S. Feedback-aided self-regulation of skin temperature with a single feedback locus: I.Acquisition and reversal training. Biofeedback and Self-Regulation 1976, 1, 147-168.

TENG, E.L., McNEAL, D.R., KRALJ, A., & WATERS, R.L. Electrical stimulation and feedback training: Effects on the voluntary control of paretic muscles. Archives of Physical Medicine and Rehabilitation 1976, 57, 228-233.

THORNDIKE, E.L. Animal Intelligence. London: Macmillan, 1911.

TURING, A.M. On computable numbers, with an application to the Entscheidungs problem. Proceedings of the London Mathematical Society II 1937, 42, 230-265.

TWITCHELL, T.E. The restoration of motor function following hemiplegia in man. Brain 1951, 74 443-480.

VOAS, R.B. Generalisation and consistency of muscle tension level. Unpublished doctoral dissertation. University of California at Los Angeles, 1952.

WAHLE, H. Zur Prognose der Hemiplegie und zum Rehabilitationspotential des Hemiplegikers. Lebensversicherungsmedezin 1973, 25, 116-118.

WALSH, K.W. Neuropsychology. Edinburgh: Churchill Livingstone, 1978.

WALTERS, C.E. Interaction of the body and its segments. American Journal of Physical Medicine 1967, 46, 1.

WALTON, J.N. Brain's Diseases of the Nervous System. (8th edn) Oxford: Oxford University Press, 1977.

WEBER, E.H. De pulsu, resorptione, auditu et tactu: annotationes anatomical et physiological (1834). Excerpts in English translation in: Dennis, W. (ed.) Readings in the History of Psychology. New York: Appleton-Century-Crofts, 1948 (194-196).

WEISS, T., & ENGEL, B.T. Operant conditioning of heart rate in patients with premature ventricular contractions. Psychosomatic Medicine 1971, 33, 301-321.

WHISNANT, J.P., FITZGIBBON, J.P., KURLAND, L.T., & SAYRE, G.P. Natural history of stroke in Rochester Minnesota, 1945 through 1954. Stroke 1971, 2, 11.

WICKRAMASEKERA, I. Instructions and E.M.G. feedback in systematic desensitisation: A case report. Behaviour Therapy 1972, 3, 460-465.

WIENER, N. Cybernetics. New York: Wiley, 1949.

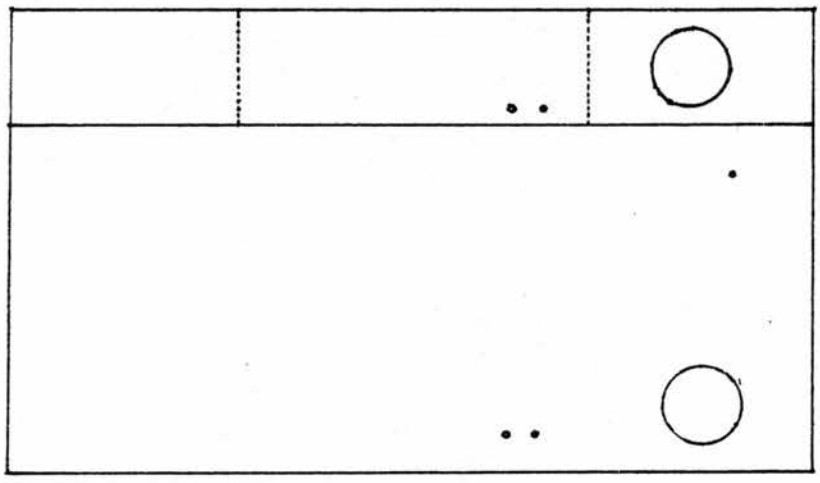
WOLF, S.L., BAKER, M.P., & KELLY, J.L. E.M.G. biofeedback in stroke: Effect of patient characteristics. Archives of Physical Medicine and Rehabilitation 1979, 60, 96-102.

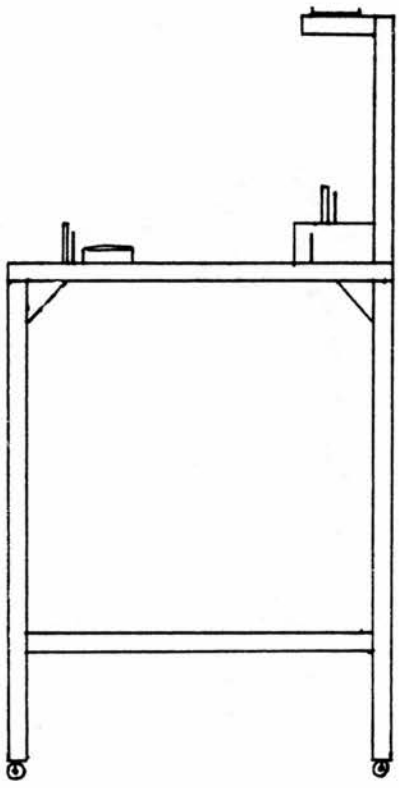
APPENDICES

LIST OF APPENDICES

APPENDIX A

Plan view and side elevation of apparatus trolley





APPENDIX B

Upper Extremity Function Test:
Inter-item correlation matrix

Intercorrelation of Original U.E.F.T. Items

	01	02	03	04	05	06	07	08	09	10	11
01		0.93	0.99	0.91	0.88	0.86	0.93	1.00	0.66	0.66	0.64
02			0.94	0.99	0.92	0.90	0.98	0.93	0.75	0.75	0.63
03				0.92	0.86	0.84	0.92	0.99	0.65	0.65	0.63
04					0.90	0.91	0.96	0.91	0.80	0.80	0.67
05						0.99	0.92	0.88	0.73	0.79	0.67
06							0.91	0.86	0.78	0.84	0.72
07								0.93	0.77	0.77	0.64
08									0.66	0.66	0.64
09										0.87	0.88
10											0.89
11											

	12	13	14	15	16	17	18	19	20	21	22
01	0.65	0.64	0.64	0.64	0.65	0.64	0.65	0.55	0.65	0.53	0.64
02	0.59	0.63	0.57	0.58	0.59	0.63	0.59	0.49	0.59	0.48	0.58
03	0.65	0.63	0.64	0.64	0.65	0.63	0.65	0.54	0.65	0.53	0.64
04	0.62	0.67	0.61	0.62	0.62	0.67	0.62	0.52	0.62	0.51	0.62
05	0.57	0.67	0.62	0.56	0.57	0.67	0.57	0.48	0.57	0.53	0.56
06	0.61	0.72	0.66	0.60	0.61	0.72	0.61	0.51	0.61	0.57	0.60
07	0.59	0.64	0.59	0.59	0.59	0.64	0.59	0.50	0.59	0.49	0.59
08	0.65	0.64	0.64	0.64	0.65	0.64	0.65	0.55	0.65	0.53	0.64
09	0.80	0.88	0.80	0.79	0.80	0.88	0.80	0.67	0.80	0.67	0.79
10	0.81	0.89	0.81	0.80	0.81	0.89	0.81	0.68	0.81	0.68	0.80
11	0.97	1.00	0.98	0.95	0.97	1.00	0.97	0.81	0.97	0.82	0.95

	23	24	25	26	27	28	29	30	31	32
01	0.54	0.54	0.79	0.60	0.86	0.74	0.80	0.92	0.89	0.76
02	0.48	0.48	0.84	0.63	0.90	0.79	0.71	0.85	0.82	0.75
03	0.53	0.53	0.77	0.59	0.84	0.72	0.79	0.90	0.87	0.81
04	0.52	0.52	0.84	0.59	0.91	0.82	0.73	0.83	0.80	0.74
05	0.47	0.47	0.95	0.65	0.95	0.90	0.66	0.80	0.87	0.73
06	0.50	0.50	0.96	0.60	0.96	0.94	0.67	0.78	0.86	0.71
07	0.49	0.49	0.87	0.66	0.92	0.82	0.72	0.88	0.85	0.72
08	0.54	0.54	0.79	0.60	0.86	0.74	0.80	0.92	0.89	0.76
09	0.66	0.66	0.76	0.23	0.80	0.80	0.78	0.59	0.58	0.50
10	0.67	0.67	0.84	0.36	0.80	0.88	0.73	0.59	0.59	0.46
11	0.80	0.80	0.72	0.17	0.68	0.75	0.85	0.57	0.58	0.47

	12	13	14	15	16	17	18	19	20	21	22
12		0.97	0.98	0.98	1.00	0.97	1.00	0.84	1.00	0.82	0.98
13			0.98	0.95	0.97	1.00	0.97	0.81	0.97	0.82	0.95
14				0.97	0.98	0.98	0.98	0.83	0.98	0.84	0.97
15					0.98	0.95	0.98	0.92	0.98	0.90	0.96
16						0.97	1.00	0.84	1.00	0.82	0.98
17							0.97	0.81	0.97	0.82	0.95
18								0.84	1.00	0.82	0.98
19									0.84	0.98	0.80
20										0.82	0.98
21											0.77

	23	24	25	26	27	28	29	30	31	32
12	0.83	0.83	0.61	0.13	0.58	0.64	0.90	0.59	0.54	0.45
13	0.80	0.80	0.72	0.17	0.68	0.75	0.85	0.57	0.58	0.47
14	0.81	0.81	0.66	0.13	0.63	0.69	0.87	0.58	0.59	0.49
15	0.90	0.90	0.60	0.18	0.57	0.63	0.89	0.58	0.53	0.44
16	0.83	0.83	0.61	0.13	0.58	0.64	0.90	0.59	0.54	0.45
17	0.80	0.80	0.72	0.17	0.68	0.75	0.85	0.57	0.58	0.47
18	0.83	0.83	0.61	0.13	0.58	0.64	0.90	0.59	0.54	0.45
19	0.98	0.98	0.51	0.26	0.49	0.54	0.76	0.50	0.46	0.38
20	0.83	0.83	0.61	0.13	0.58	0.64	0.90	0.59	0.54	0.45
21	0.96	0.96	0.57	0.26	0.54	0.59	0.72	0.48	0.51	0.42
22	0.81	0.81	0.60	0.14	0.57	0.63	0.89	0.58	0.53	0.44

	23	24	25	26	27	28	29	30	31	32
23		1.00	0.50	0.28	0.48	0.53	0.74	0.49	0.45	0.37
24			0.50	0.28	0.48	0.53	0.74	0.49	0.45	0.37
25				0.62	0.92	0.98	0.71	0.74	0.82	0.74
26					0.52	0.48	0.28	0.71	0.71	0.61
27						0.93	0.68	0.76	0.83	0.70
28							0.72	0.64	0.73	0.66
29								0.72	0.65	0.64
30									0.94	0.80
31										0.86
32										

APPENDIX C

Upper Extremity Function Test:

Intra-scale correlations

INTERCORRELATION OF CONSTITUENT ITEMS OF ORIGINAL U.E.F.T. "GRASP SUBSCALE

	1	2	3	4
1		0.93	0.99	0.91
2			0.94	0.99
3				0.92
4				

INTERCORRELATION OF CONSTITUENT ITEMS OF ORIGINAL U.E.F.T. "GRIP" SUBSCALE

	5	6
5		0.99
6		

Intercorrelation of Constituent Items of Original U.E.F.T. "Pinch" Subscale

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
8		0.66	0.66	0.64	0.65	0.64	0.64	0.64	0.65	0.64	0.65	0.55	0.65	0.53	0.64	0.54	0.54
9			0.87	0.88	0.80	0.88	0.80	0.79	0.80	0.88	0.80	0.67	0.80	0.67	0.79	0.66	0.66
10				0.89	0.81	0.89	0.81	0.80	0.81	0.89	0.81	0.68	0.81	0.68	0.80	0.67	0.67
11					0.97	1.00	0.98	0.95	0.97	1.00	0.97	0.81	0.97	0.82	0.95	0.80	0.80
12						0.97	0.98	0.98	1.00	0.97	1.00	0.84	1.00	0.82	0.98	0.83	0.83
13							0.98	0.95	0.97	1.00	0.97	0.81	0.97	0.82	0.95	0.80	0.80
14								0.97	0.98	0.98	0.98	0.83	0.98	0.84	0.97	0.81	0.81
15									0.98	0.95	0.98	0.92	0.98	0.90	0.96	0.90	0.90
16										0.97	1.00	0.84	1.00	0.82	0.98	0.83	0.83
17											0.97	0.81	0.97	0.82	0.95	0.80	0.80
18												0.84	1.00	0.82	0.98	0.83	0.83
19													0.84	0.98	0.80	0.98	0.98
20														0.82	0.98	0.83	0.83
21															0.77	0.96	0.96
22																0.81	0.81
23																	1.00

INTERCORRELATION OF CONSTITUENT ITEMS OF ORIGINAL U.E.F.T. "PLACING" SUBSCALE

	25	26
25		0.62
26		

INTERCORRELATION OF CONSTITUENT ITEMS OF ORIGINAL U.E.F.T. "SUPINATION AND PRONATION" SUBSCALE

	27	28	29	30	31	32
27		0.93	0.68	0.76	0.83	0.70
28			0.72	0.64	0.73	0.66
29				0.72	0.65	0.64
30					0.94	0.80
31						0.86
32						

APPENDIX D

Armtest: Particulars of Guttman scales derived from experimental data

GUTTMAN SCALES: ARMTEST

DATA FROM IMPAIRED AND UNIMPAIRED SIDE

BOTH EXAMINERS POOLED

Notes

1. Items in descending order of difficulty.
2. Cutting scores in brackets.
3. Item numbers refer to Carroll U.E.F.T. Table IV(2).

GRASP

Item 1 (1)
Item 8 (1)
Item 7 (1)
Item 2 (1)
Item 3 (1)
Item 4 (1)

Coefft. of reproducibility = 0.99
Coefft. of scalability = 0.94

Item 1 (3)
Item 8 (3)
Item 4 (3)
Item 7 (3)
Item 3 (3)
Item 2 (3)

Coefft. of reproducibility = 0.98
Coefft. of scalability = 0.95

GRIP

Item 28 (1)
Item 25 (1)
Item 6 (1)
Item 5 (1)

Coefft. of reproducibility = 0.99
Coefft. of scalability = 0.94

Item 28 (3)
Item 25 (3)
Item 6 (3)
Item 5 (3)

Coefft. of reproducibility = 1.00
Coefft. of scalability = 1.00

PINCH

Item 19 (1)
Item 18 (1)
Item 17 (1) Coefft. of reproducibility = 0.99
Item 11 (1) Coefft. of scalability   = 0.98
Item 10 (1)
Item 9 (1)

Item 19 (3)
Item 18 (3)
Item 17 (3) Coefft. of reproducibility = 1.00
Item 11 (3) Coefft. of scalability   = 1.00
Item 10 (3)
Item 9 (3)

GROSSMT

Item 31 (1) Coefft. of reproducibility = 0.98
Item 32 (1) Coefft. of scalability   = 0.92
Item 30 (1)

Item 30 (3) Coefft. of reproducibility = 1.00
Item 31 (3) Coefft. of scalability   = 1.00
Item 32 (3)

APPENDIX E

Armtest: Cross-validation of Guttman scales using data from Carroll

GUTTMAN SCALES: ARMTEST

CROSS-VALIDATION: DATA FROM CARROLL

Notes

1. Items in descending order of difficulty.
2. Cutting scores in brackets.
3. Item numbers refer to Carroll U.E.F.T. Table IV(2).

GRASP

Item 1 (1)
Item 2 (1)
Item 8 (1)
Item 7 (1)
Item 3 (1)
Item 4 (1)

Coefft. of reproducibility = 0.94
Coefft. of scalability = 0.78

Item 1 (3)
Item 2 (3)
Item 3 (3)
Item 4 (3)
Item 7 (3)
Item 8 (3)

Coefft. of reproducibility = 0.97
Coefft. of scalability = 0.78

GRIP

Item 28 (1)
Item 25 (1)
Item 6 (1)
Item 5 (1)

Coefft. of reproducibility = 0.89
Coefft. of scalability = 0.58

Item 28 (3)
Item 25 (3)
Item 6 (3)
Item 5 (3)

Coefft. of reproducibility = 0.92
Coefft. of scalability = 0.56

PINCH

Item 19 (1)
Item 18 (1)
Item 11 (1)
Item 17 (1)
Item 10 (1)
Item 9 (1)

Coefft. of reproducibility = 0.93
Coefft. of scalability = 0.84

Item 19 (3)
Item 18 (3)
Item 11 (3)
Item 17 (3)
Item 10 (3)
Item 9 (3)

Coefft. of reproducibility = 0.98
Coefft. of scalability = 0.87

GROSSMT

Item 31 (1)
Item 32 (1)
Item 30 (1)

Coefft. of reproducibility = 0.96
Coefft. of scalability = 0.73

Item 30 (3)
Item 31 (3)
Item 32 (3)

Coefft. of reproducibility = 1.00
Coefft. of scalability = 1.00

APPENDIX F

Armtest: Inter-scale correlations

ARMTEST

Inter-scale Pearson correlations
(Impaired side only)

(1) Rater 1

	GRASP	GRIP	PINCH	GROSSMT.	TOTAL
GRASP		0.8742	0.7077	0.8885	0.9542
GRIP			0.7593	0.8089	0.9415
PINCH				0.5896*	0.8578
GROSSMT.					0.8826
TOTAL					

Key

*: not significant at $p<0.001$

ARMTEST

Inter-scale Pearson correlations
(Impaired side only)

(2) Rater 2

	GRASP	GRIP	PINCH	GROSSMT.	TOTAL
GRASP		0.9402	0.7416	0.8918	0.9517
GRIP			0.8104	0.9404	0.9736
PINCH				0.7879	0.8955
GROSSMT.					0.9462
TOTAL					

all significant at $p<0.001$

APPENDIX G

Activities of Daily Living investigation: Test equipment used

ACTIVITIES OF DAILY LIVING TEST

Standard Equipment Used

Item no.	Description	Manufacturer/Type
3	Wheelchair	Zimmer Orthopaedic
4	Door lever	Assa
5	Light switch	M.K.
6	Springlatch lock Door knob	Legge unknown
9	Ironing board	Jonelle
10	Electric iron	Morphy Richards Steam Spray
11	Sweeping brush	N.H.S. issue
12	Short brush & dustpan	Addis
13	Mop	Prestige Minit Mop
14	Bin	N.H.S. issue
15	Electric coin meter	S.S.E.B. issue
17	Bus	Leyland single deck
18	Car	Citroen G.S.
24	Dressing gown	Hospital issue
47	Scissors	Sheffield 6"
48	Electric shaver	Ronson battery operated
49	Lipstick	Yardley
50	Nail clippers	Boots
51	Hair brush & comb	Addis
53	Electric 13 Amp plug	M.K.
59	Carpet sweeper	Ewbank
71	Toothbrush	Tek
73	Razor Shaving stick	Pal Injecto-Matic Palmolive

Item no.	Description	Manufacturer/Type
75	Glass in plastic holder	Pyrex
76	Spoon	N.H.S. issue
78	Knife & fork	N.H.S. issue
81	Jar	Nescafe 16oz.
84	Tin Tin opener	Heinz Baked Beans 5oz. Rudman-Darlington (wall mounted)
85	Gas cooker	New World 41
86	Kettle	Prestige trigger action
88	Electric kettle	Russell Hobbs
89	Teapot	Tower Brand 3 pint
90	Teacup & saucer	N.H.S. issue
91	Plate	N.H.S. issue
92	Trolley	As made at Simon Square Centre, Edinburgh
97	Saucepan	Tower Brand
99	Potato peeler	similar to Skyline
100	Grater	Tala
10	Kitchen scales	Krups
102	One-hand beater	Skyline Whisk
103	Sieve	Skyline
105	Gas igniter	Plessey piezo electric
106	Dish	Pyrex

APPENDIX H

Activities of Daily Living investigation:

Aids and assistive devices used

ACTIVITIES OF DAILY LIVING TEST

Standard aids (assistive devices) used

Item no.	Description	Manufacturer/Type
1	Walking frame or tripod	Zimmer
16	Extra handrail	unknown
19, 20, 21, 24.	Dressing stick	Astley Ainslie Hospital Day Unit Workshop
23	Elastic laces, long shoehorn	Nomeq
25, 26	Hand reacher	Carters
35	Elastic tie	unknown
46	Sewing frame	A.A.H. Day Unit w/shop
56	Match box holder	A.A.H. Day Unit w/shop
60	Frame or rail	Scandia
65-70	Towel with loops	alteration made at A.A.H. Day Unit
74	Bathboard, seat & rail	Carters
77-78	Spreader board, Friction pad	A.A.H. Day Unit w/shop Dycem
80	Suction egg-cup	Homecraft Supplies
82	Screw cap bottle opener	Undoit (Murell Ltd.)
84	Stand for can opener	A.A.H. Day Unit w/shop
91	One-hand tray	Dycem
94	Tap turner	Tapeze
99	Spike board	A.A.H. Day Unit w/shop
100	Grater stand, suction fitment	A.A.H. Day Unit w/shop
102, 104	Friction pad	Dycem

APPENDIX I

Guttman-scaled A.D.L. for hemiplegia

A Guttman-scaled A.D.L. for Hemiplegia

Patient ..... Date .....

Examiner ..... Side Impaired .....

Scoring:
- 0: Can perform no part of test
- 1: If applicable - performs test partially, can complete only with major assistance.
- 2: If applicable - completes test with slight help or supervision recommended for safety.
- 3: If applicable - completes test with specified mechanical aid.
- 4: Completes test safely and independently but takes a longer time or has some difficulty.
- 5: Performs test normally.

Instructions to Examiner:

This A.D.L. measure has been specially constructed to speed up testing time. It is divided into twelve sub-scales. Items within each sub-scale are credited as passes, if the patient attains or exceeds the score point indicated in brackets following that item. Items within each sub-scale are ordered in such a way that if the patient passes the first item (the most difficult) he would almost certainly pass every other item at the score levels indicated. Thus, if a pass is obtained on Item 1 the patient is credited as having passed all items of that sub-scale, at least at the score levels indicated, without having to be tested on the remaining sub-scale items. Items so credited should be indicated by a tick. If the patient scores a fail on Item 1, then Item 2 is next administered. Item 2 is the easiest item in that sub-scale, and if the patient fails to pass that item at the specified score level, then he is unlikely to achieve a pass on any item in that sub-scale. Thus, he is credited with a zero score for that sub-scale, and you should move to the next sub-scale.

Should the patient who has failed to pass Item 1 at the specified level, succeed in passing Item 2, then subsequent items within the sub-scale should be administered in the order laid out in the form. Testing on that sub-scale can safely be terminated when the patient fails to pass an item at the specified score level.

This sounds complicated to explain, but is easy in practice. The result is an average saving of approximately 50% in testing time.

EXAMPLES

Example 1:

(5)	✓	A.D.L. 26	(4)	STOCKINGS TIGHTS OR SOCKS ON & OFF
	✓	A.D.L. 49	(4)	ELECSHAVE OR LIPSTICK
	✓	A.D.L. 44	(4)	OPERATE TELEPHONE
	✓	A.D.L. 96	(4)	DRY CROCKERY
		TOTAL 4		

The patient scored (5) for item one, and hence was credited as having passed all other items in the subscale.

Example 2:

(2)	✗	A.D.L. 52	(4)	STRIP & MAKE BED
(2)	✗	A.D.L. 95	(4)	WASH UP CROCKERY
	✗	A.D.L.109	(4)	CLEAN UTENSILS
	✗	A.D.L. 97	(4)	TAKE PAN & DISH FROM LOW PRESS
		TOTAL 0		

The patient scored (2) on item one, and (2) on item two. Thus he is considered to have failed all items in the subscale.

Example 3:

(3)	✗	A.D.L. 60	(4)	GET ON & OFF TOILET
(3)	✓	A.D.L. 60	(3)	GET ON & OFF TOILET
(1)	✗	A.D.L.105	(4)	LIGHT OVEN
	✗	A.D.L. 12	(4)	SWEEP WITH SHORT BRUSH & DUSTPAN
	✗	A.D.L. 11	(4)	SWEEP WITH LONG BRUSH
	✗	A.D.L. 13	(4)	WET MOP PART FLOOR
	✗	A.D.L. 31	(4)	GET UP FROM FLOOR
		TOTAL 1		

The patient scored (3) on item one, and (3) on item two, but failed subsequent items on the subscale.

GUTTMAN SCALE: BALANCE

(CUTTING SCORES IN BRACKETS)

A.D.L.	9	(4)	FETCH & ASSEMBLE IRONING BOARD
A.D.L.	1	(3)	STANDING BALANCE
A.D.L.	2	(3)	WALK 20 METRES
A.D.L.	1	(4)	STANDING BALANCE
A.D.L.	29	(4)	(STANDING) GET STICK FROM FLOOR
A.D.L.	81	(4)	TAKE PLATE FROM HIGH PRESS
A.D.L.	16	(3)	ASCEND & DESCEND 5 STEPS
A.D.L.	16	(4)	ASCEND & DESCEND 5 STEPS
A.D.L.	17	(4)	GET ON & OFF BUS
A.D.L.	2	(4)	WALK 20 METRES
A.D.L.	50	(4)	CUT TOE & FINGER NAILS
TOTAL			

GUTTMAN SCALE: TWO HANDS

A.D.L.	84	(4)	OPEN TIN
A.D.L.	40	(4)	FASTEN ZIP BOARD
A.D.L.	39	(4)	FASTEN BUCKLE BOARD
A.D.L.	107	(4)	TAKE HOT DISH FROM OVEN
A.D.L.	80	(4)	EAT BOILED EGG
A.D.L.	91	(4)	CARRY LADEN TRAY TO LOW TOP
TOTAL			

GUTTMAN SCALE: ONE HAND

A.D.L.	84	(3)	OPEN TIN
A.D.L.	108	(3)	SERVE ONTO PLATE
A.D.L.	104	(3)	BEAT ALL TOGETHER
A.D.L.	79	(3)	EAT WITH FORK
A.D.L.	37	(4)	FASTEN BUTTONS ON BOARD
A.D.L.	30	(4)	ON & OFF CHAIR
A.D.L.	15	(4)	OPERATE COIN METER
A.D.L.	21	(4)	LOWER GARMENT ON & OFF OVER FEET
A.D.L.	20	(4)	UPPER GARMENT (FRONT OPENING) ON & OFF
A.D.L.	10	(4)	IRON TOWEL
TOTAL			

GUTTMAN SCALE: TWO WRISTS

A.D.L.	99	(4)	PEEL & CUT POTATOES
A.D.L.	79	(4)	EAT WITH FORK
A.D.L.	104	(4)	BEAT ALL TOGETHER
A.D.L.	7	(4)	WASH, RINSE & WRING TEATOWEL
A.D.L.	60	(4)	GET ON & OFF TOILET
TOTAL			

GUTTMAN SCALE: SHOULDERS

A.D.L.	60	(4)	GET ON & OFF TOILET
A.D.L.	60	(3)	GET ON & OFF TOILET
A.D.L.	105	(4)	LIGHT OVEN
A.D.L.	12	(4)	SWEEP WITH SHORT BRUSH & DUSTPAN
A.D.L.	11	(4)	SWEEP WITH LONG BRUSH
A.D.L.	13	(4)	WET MOP PART FLOOR
A.D.L.	31	(4)	GET UP FROM FLOOR
TOTAL			

GUTTMAN SCALE: ARMS

A.D.L.	8	(4)	PLACE ON PULLEY & RAISE
A.D.L.	82	(4)	OPEN SCREW TOP JAR
A.D.L.	69	(4)	SIMULATE WASHING, LEGS & FEET
A.D.L.	86	(4)	FILL KETTLE
A.D.L.	51	(4)	BRUSH & COMB HAIR
A.D.L.	42	(4)	TAKE MONEY FROM PURSE
A.D.L.	3	(4)	PROPEL WHEELCHAIR
A.D.L.	19	(4)	UPPER GARMENT ON & OFF OVER HEAD
A.D.L.	24	(4)	DRESSING GOWN ON & OFF
A.D.L.	14	(4)	MOVE BIN ACROSS FLOOR
TOTAL			

GUTTMAN SCALE: PINCH

A.D.L.	78	(4)	CUT & EAT BREAD (KNIFE & FORK)
A.D.L.	77	(3)	BUTTER BREAD
A.D.L.	100	(3)	GRATE & WEIGH CHEESE
A.D.L.	67	(3)	SIMULATE WASHING ARMS TO NAILS
A.D.L.	67	(4)	SIMULATE WASHING ARMS TO NAILS
A.D.L.	100	(4)	GRATE & WEIGH CHEESE

GUTTMAN SCALE: PINCH (CONT.)

A.D.L.	77	(4)	BUTTER BREAD
A.D.L.	78	(3)	CUT & EAT BREAD (KNIFE & FORK)
TOTAL			

GUTTMAN SCALE: GRIPFORCE

A.D.L.	54	(4)	CARRY COAL BUCKET
A.D.L.	90	(4)	POUR TEA INTO CUP
A.D.L.	57	(4)	DUST WINDOWSILL
A.D.L.	89	(4)	POUR HOT WATER IN TEAPOT
A.D.L.	85	(4)	TURN GAS HOTPLATE ON & OFF
A.D.L.	62	(4)	FLUSH TOILET
A.D.L.	106	(4)	INSERT DISH IN OVEN
A.D.L.	87	(4)	PUT KETTLE ON HOTPLATE
A.D.L.	83	(3)	LIFT BAG OF TINS ACROSS ROOM
A.D.L.	59	(4)	USE CARPET SWEEPER
A.D.L.	6	(4)	OPERATE DOOR KNOB & KEY
A.D.L.	83	(4)	LIFT BAG OF TINS ACROSS ROOM
TOTAL			

GUTTMAN SCALE: ADROIT

A.D.L.	26	(4)	STOCKINGS TIGHTS OR SOCKS ON & OFF
A.D.L.	49	(4)	ELECSHAVE OR LIPSTICK
A.D.L.	44	(4)	OPERATE TELEPHONE
A.D.L.	96	(4)	DRY CROCKERY
TOTAL			

GUTTMAN SCALE: COMPLEX 'A'

A.D.L.	52	(4)	STRIP & MAKE BED
A.D.L.	95	(4)	WASH UP CROCKERY
A.D.L.	109	(4)	CLEAN UTENSILS
A.D.L.	97	(4)	TAKE PAN & DISH FROM LOW PRESS
TOTAL			

GUTTMAN SCALE: COMPLEX 'B'

A.D.L.	70	(4)	SIMULATE WASH & DRY HAIR
A.D.L.	92	(4)	PUT CUP & PLATES ON TROLLEY
A.D.L.	103	(4)	DRAIN POTATOES
A.D.L.	53	(4)	PLUG IN TO LOW POINT & SWITCH ON
A.D.L.	72	(4)	IN, OUT & SOAK DENTURES
TOTAL			

GUTTMAN SCALE: PLAN

A.D.L.	18	(4)	GET IN & OUT OF CAR
A.D.L.	43	(4)	PRODUCE COINS TO ORDER
A.D.L.	55	(4)	PREPARE OPEN FIRE
A.D.L.	47	(4)	USE SCISSORS
A.D.L.	98	(4)	FOLLOW RECIPE
A.D.L.	56	(3)	STRIKE MATCH
TOTAL			